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THE FREE WORLD'S FIRST LINE OF DEFENSE

AN ADDRESS BY GWILYM A. PRICE

PRESIDENT, WESTINGHOUSE ELECTRIC CORPORATION

AT THE

ANNUAL BANQUET OF THE

AMERICAN SOCIETY OF NAVAL ENGINEERS

HOTEL STATLER

WASHINGTON, D. C., FRIDAY, MAY 1, 1953

Thank you, Admiral Mills. President Wallin—Members and Guests of the Society of Naval Engineers.

It is a pleasure to be here tonight, and I am greatly complimented that you have asked me to speak at this annual banquet of your Society.

As part of my homework for this occasion, I have collected and read all the speeches made at the annual banquets of this Society since the war. I am most deeply impressed by those addresses that were delivered by your own people on the work of the Navy. I wonder, in fact, how a mere businessman could begin to approach their interest or excellence.

I had hoped to say something of the fine cooperation that has developed between your Service and private industry, but I find that Admiral Carney did that here four years ago far more ably than I can.

My own contacts with the armed forces over the past dozen years, and specifically with the Naval Engineers, have always been pleasant. I have seen my company's business carried through channels with good judgment and dispatch. This has led me to a radical thought. Can it be that the operating agencies of the armed forces and their top brass are not quite so inefficient and bungling as the experts outside the services tell us daily?

Each of you, I suppose, has smarted under criticism of your Service which you know to be unjust and which you are powerless to answer; and you have probably balanced that criticism in the scale with the higher income and easier life available to you in private industry. I think there are more business men than you realize who understand your work and sympathize with your situation.

It is an American habit, and sometimes an American fault, to demand perfection—and to expect it to be delivered on gold plates immediately, no matter how colossal the job to be done. We are an impatient people, and we are prone to judge any situation in terms of absolute values and ideal objectives rather than in terms of progress and relative improvement. We want to accomplish too much, too soon, too easily. Congress, for instance, passes a law that directs the armed services to use a single catalog system in buying the two and a half million items used to arm and equip the military forces; and the nation assumes that that takes care of *that*. I am not an engineer, but I know something about purchasing, and I know that you cannot create a procurement catalog in a multi-billion dollar enterprise simply by legal enactment.

We do ourselves harm when we apply this demand for perfection, this all-or-nothing ideal, to the operating agencies of a military service; but we endanger our very existence when we extend it, as we have done through most of this century, to world events and the inter-relationship of nations. It has caused us, as a people, to shuttle wildly between hope and despair, between promise and disillusionment, back and forth between the extremes of isolationism and internationalism. It is a chief reason why we are generally engaged either in a mad scramble to rearm ourselves or an equally mad scramble to disarm.

We in America need to learn patience and moderation. We need to learn and apply the advice of a great man who said: "The American tendency is to try to get finality and quick decisions of age-old problems. There is no finality to the stream of history—no black and white decisions. The stream of history is always flowing and problems between nations never end." His name was James Forrestal.

Our generation has made many mistakes, many of them serious, some of them shameful; but we have, I think, turned a corner and against evil forces have begun a counter-march that should decide basic issues for generations to come. We have begun to win what Admiral Noble two years ago described to you as "Three Quarters Peace, One Quarter War." Totalitarianism has been turned up to the sun and is a dying concept, both as a political philosophy and as a working economy.

Now, as the counter-forces begin to surge up and the balance of military power in the world is again restored, our people are beset with new fears. Two questions seem to be in everyone's mind.

We worry, first, if we will disarm again, go to sleep, and be caught off guard by a waiting enemy who talks of peace solely for the strategic advantage it can give him. The answer is simply that we *must not* disarm and relax before we are absolutely sure we live in a world in which it is safe to sleep without arms. This is a great country to have stood up so well under the treatment we have given it in the past dozen years, but we must not run the risk of subjecting it to such extremes again. Santayana said: "Those who forget their history are doomed to repeat it"; to which someone else has added: "And every time you repeat it, the price goes up."

The other fear we have heard is that a business slump may follow a settlement with the Communists. The fear is not unnatural. Our economy is undergoing a vast expansion—the third since 1940. Our increase in industrial expansion over the past three years just about equals our entire net increase in production for the twenty years from 1920 to 1940. Nothing like that has

ever happened before in history, and there is some concern among our people how the product of this expanded economy can be absorbed again into the civilian stream.

We Americans have a number of effective weapons we can use in this coming effort to convert our expanded productive capacity. We can absorb most of it simply by raising our national standard of living by, say, ten per cent. We can improve our selling and distribution facilities to help do this. When the heavy burden of federal taxes is lightened, funds will be released that should create a sustained buying wave. There are almost unlimited possibilities for new and better products and for cheaper production through the application of science and technology. Better productivity, of course, is the decisive element. It can steadily reduce prices to the point where the product can be sold in mass volume. Productivity is the reason, as Mr. Irving Olds has pointed out, why rabbit is cheaper than mink.

Much more is at stake here than our own stability or the solvency of our own economy. The good health of the American economic system is intimately bound up with the good health of many other national economies. It is the free world's first line of defense. It is the hope of the peoples everywhere who have been entrapped behind Communist border guards, mine fields and barbed wire. If we are to fulfill our unsought mission as the first line of defense of freedom, we must retain our economic vigor. Charles Kettering told this gathering in 1947 of the great and surprising discovery the world had made after the war. It learned that if you want to provide your friends with milk, you have to have a cow.

The stability and solvency of the rest of the free world are important to us, too. In order to attain these goals, we have sent abroad money, goods and technical aid. In a gesture unique in history, we have opened our factories to productivity teams from abroad. In strengthening our associate nations, we have already gone so far as to jeopardize, if not totally sacrifice, our competitive position in world markets for highly engineered products in which labor cost is a primary factor. Since 1945 we have given our friends more than 35 billion dollars. As Paul Hoffman once pointed out, you take a billion here and a billion there and it begins to run into money.

I think we acted wisely in carrying out that post-war program. It helped some good people get back on their feet and in the process it helped to win political victory for us where we needed it. I hope we will continue aid to our allies, particularly in its present form of building American arms in foreign factories under the offshore procurement program.

There is now considerable weight behind another proposal for aiding our overseas allies—to change our trade and tariff policy

drastically, so as to admit a much heavier flow of imports. Several national organizations have backed this proposal, some of them recommending the complete elimination of import duties. The Mutual Security Agency last fall had a plan by which our tariffs would be cut ten per cent across the board each year for ten years. The Detroit Board of Commerce last November asked that all import duties be repealed, including the one protecting automobiles. Our basic tariff law will expire next month, and we shall hear more of this proposal as the Congress acts on the President's request to continue that law for another year.

Proponents of this new tariff policy say that it would "raise efficiency, reduce aid abroad and taxes at home, and thus give American consumers billions more to spend, maintain employment in export industries, and enable the nation to consume more without working harder." The proposal is being presented under the slogan "Trade, Not Aid." At the worst, they say—"A few inefficient organizations may suffer"—"A tiny segment of our economy may be injured or dislocated"— and "There may be real or fancied injury to specific groups which represent special interests and are, therefore, highly organized."

It is a plausible argument and one that is being widely accepted by businessmen, editorial writers, government officials, and other men of good will. To oppose it now is a little like attacking motherhood and endorsing sin. At this point, however, I think we might well consider the opinion of Justice Holmes, who said: "No general proposition is worth a damn." We need a little of the skepticism that Cordell Hull, father of the Reciprocal Tariff Law, is said to have shown one day on a train ride through his native Tennessee. A friend said to him, pointing, "Those sheep have just been sheared." To which Mr. Hull replied: "Sheared on this side, anyway."

Current proposals for complete, unilateral free trade spring from the noblest and purest of motives, but I believe they are over-simplified and wrong. They are another example of our impulse to try to do too much, too soon, too easily. I believe such proposals, if carried out, could harm our economic stability, and I *know* they would endanger our military security. Because I believe this so strongly, I have undertaken the thankless task of saying here words of opposition that I feel need to be spoken. Because I know that the paramount concern of the Naval Engineer is the preservation of our national security, I am sure you will agree with me that what I am about to say is in the direct line of your professional and patriotic interest.

We Americans have come a long way, of course, in the direction of free trade. In 1934, the average rate on dutiable imports on all products was more than 25 per cent; by 1951 it had dropped to 13.3 per cent. More than half of our imports are admitted

duty-free. Imports have risen steadily and substantially since the war. Presumably they will continue to rise. The Materials Policy Commission, for example, has estimated that we will have to triple our imports of raw materials by 1975.

This is a good record, from the point of view of any trade liberal who does not expect miracles. Probably the American people, through their President, Congress and Tariff Commission, will want to continue that slowly declining rate on imports, on a selective basis. But to eliminate duties entirely, as is being seriously proposed by responsible persons and organizations, will beyond any question of doubt disrupt critical parts and areas of the national economy, with serious consequences both here and abroad.

I do not refer to disruption of those modest-sized industries that are cited over and over again—and unfairly, I think—by proponents of absolute free trade as ones we can conveniently do without—the briar pipe industry, felt hats, fountain pens, clothespins, lichee nuts, narcissus bulbs and certain kinds of cheese. I speak rather of those vital defense industries that seem always to be forgotten in this debate, but which certainly would be deeply and adversely affected by a surge of imports—indeed, have already been so affected. I have in mind such industries as machine tools, optics, heavy electrical power equipment, precision instruments, and others whose circumstances may be similar but with which I am not familiar.

These are not "a few inefficient organizations." They are not "a tiny segment of the economy." They are not even "special interests," for they make up a substantial part of the nation's arduously created capital industry. These companies are not owned by a few rich men who personally stand to make millions by unreasonably high tariffs. They are owned by hundreds of thousands of stockholders and serviced by millions of employees, all of whom have a direct stake in the continued profitable operation of those companies.

But are the fears real? Are imports likely to enter in sufficient volume to dislocate American production and throw men out of work? With your permission, and because I know it best, let me cite as an example an important segment of the electrical manufacturing industry. With variation in degree and detail, it can represent the other industries I have mentioned.

This much in preliminary: To all that I say, apply whatever discount you see fit to my self-interest in this situation. I admit such interest, but I am trying to speak in the national interest as well. I shall do my best to be a truthful and honest witness to the facts.

Now, the electrical manufacturing industry has needed no preferential treatment and has asked none on the vast majority of its products. Wherever goods can be produced at a rapid rate on an assembly line, wherever mass production and mass distribution of consumer goods are concerned, the industry has demonstrated it can offset the low foreign wage rates. In radios and lamps, ranges and refrigerators, motors and washing machines, we have successfully met foreign competition in design, price and quality.

But not all products of this industry are subject to such mass production techniques. Heavy electrical power equipment is produced painstakingly in terms of a dozen units a year instead of millions. This comprises water wheel generators, turbine generators, power transformers, circuit breakers, rectifiers, and accessory equipment. These pieces are all tailor-made. They require thousands of hours of highly-skilled labor—labor that is paid an average of over $2 an hour and that represents as much as 50 per cent or more of the total production cost. Extensive and continuing basic research and development engineering are involved. This country can build these units supremely well because the industry has made large investments in plants, equipment and employee training. It is necessary to realize that the industry is geared to produce the nation's present peak requirements, and that, rather than being overloaded with business, as some have said, it may be short of orders before the production aisles are cleared of work now in progress.

At least nine European countries are now competing for the limited volume of American purchases of heavy power equipment. Some of them are nationalized companies and some are nationally subsidized. These companies pay their workers wages that in some cases are only one-fifth and in just one case are as high as 40 per cent of the comparable American wage. The American manufacturer of such heavy equipment simply cannot compete, solely on a dollar basis, with foreign companies. Such competition will be impossible until those other countries catch the American vision of a high standard of living for their workers, made possible by high wage rates and maximum mechanization.

I know of sixteen heavy power equipment projects on which both United States and foreign manufacturers entered bids in 1952. Foreign firms were awarded six of these. In dollar volume, their awards represent 42 per cent of the total amount of money involved. This may sound like a relatively small part of the total electrical equipment business of the United States, but it is concentrated in one segment of the industry that is vital to the national defense. Two projects that are now pending represent ten per cent of this country's total annual manufacturing capacity for water wheel generators. The loss of these orders could mean

more than a month's shut-down of all United States facilities in this field.

Some authorities are disposed to fortify the foreign price advantage with two other considerations favorable to the foreign bidder. They feel they are following the national policy of helping a friend in need; and they contend that the import duty is the same as extra income to our government. They ignore, of course, the adverse effects of such a policy on a vital industry; and they forget the considerably larger sum of money paid to the government as taxes by the U. S. manufacturer, by his suppliers, and by his employees, on their income.

Some proponents of "universalist" free trade do recognize the harm that their policies will bring to certain domestic industries, and their ready answer is "compensation." The Mutual Security Agency plan called for import duties to be placed in a fund for payment to injured companies, and for those companies to be given ten years in which to convert to other products or shut down. A recognized authority on the tariff question says: "The transition from our present tariff to a very low one should become a process of subsidized liquidation, thereby softening the blow for investors, employees and workers." (End of quotation.) Conceivably, that may be agreeable to the owners of the lichee nut and narcissus bulb industries; but do we want *liquidation* of our machine tool and heavy power industries? Do we want them to convert to other products?

Until now, no one, beginning with Adam Smith, the very father of free trade, has ever discussed trade policy without recognizing the requirement to preserve certain domestic industries for reasons of national security. But in almost all the speeches, articles and editorials produced during the present debate, this consideration has been forgotten or ignored.

Electric power production, of course, is vital to our national security. To implement it with foreign-made equipment, with which we have had limited experience, weakens our defense. In the event of war, the sources of such equipment could be walled off from us completely, leaving us nowhere to turn to for repairs, replacement parts, special tools, or engineering or maintenance services. One of the foreign firms awarded business in this country lies within 75 miles of the Iron Curtain. The foreign manufacturers, unlike the American companies, do not have equipment or engineering crews available in this country for such emergency work. It is even questionable whether, in critical times, some foreign groups should be free to come and go in the plants which are the key to our national existence.

Moreover, it is just not possible to maintain any industry vital to national defense with direct Federal subsidy, no matter how

generous or well-meant it is. You cannot keep an industry alive on such a basis, ready to produce critical goods quickly in an emergency. How can you keep highly paid and highly skilled employees with you? They will not shove to assembly lines, for they do not shove easily. Are they to sit around on a kind of Federal relief, forgetting all they know, learning nothing new, and training no one else, while they wait for another war? Or are they to produce machines which will have no market and will be scrapped? These are creative men much in demand in other industries, and you will not keep them at all with any such formula.

A live and healthy power equipment industry, with both its companies and their workers consistently and profitably employed, is necessary to the national security. A foreign policy that does not recognize the long-range impact of the widespread purchase of foreign-made equipment on this industry, and the resultant weakening of our national defense, is not consistent with the national interest.

This is just as true as to other American industries that are equally vital to American defense and are equally unable to survive foreign price competition. I cannot speak out of intimate knowledge of those industries, as I have presumed—without consultation with anyone outside my own company—to speak for the electrical manufacturing industry. But I know that, by the very nature of the American economy, those industries are neither inefficient nor uncompetitive. They turn out their products at reasonable prices. To buy imports in their fields simply to help nations because they deserve help, instead of on the basis of true international division of labor, is to give those nations a disguised subsidy at the same time that we harm ourselves at home.

I should like to remind those friendly nations of the statement by one of their own great leaders: "A successful export trade cannot be founded upon a starved home market." I should like to remind this distinguished audience of the so-called Political Law of Reverse Effect. Under that law, the nobler the ends, the easier it is to be careless about the means, which then bring results quite different from those intended.

We will do the nations of the free world no good if through excessive imports we force skilled people out of work and defense industries out of business. That could jeopardize our security and might cause economic disturbances here that would damage the economies of the rest of the world. It could produce a revulsive demand here for tariffs far higher than any we now have. It could bring a demand that we devalue our dollar in order to regain our favorable position in world trade.

One final word. I pray that no one will misunderstand me. I am not a so-called isolationist—I have always considered myself

internationally minded. I am not in favor of high tariffs—I am for just as low tariffs as will still permit us to maintain the economic welfare on which the national and, indeed, the international security must depend. But I am for low tariffs on a selective basis, not a whole-hog, universalist, across-the-board basis. I repeat—a selective basis.

We will do friendly nations nothing but harm if we weaken our defense by allowing good will to take the place of good sense, good economics, and good military strategy. The economic health and stability of this nation are the first line of defense of all free nations. We must not break down these defenses. In a dark hour of British need, Winston Churchill put the problem to us pointedly when he said: "The greatest contribution the United States can make toward world peace is the maintenance and growth of its own prosperity."

I thank you, Admiral Wallin, I thank all of you for inviting me to be your guest tonight, and for giving me this courteous hearing.

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Foster Wheeler Corp.	Marine Steam Generators, Condensers, Bent Tube and Straight Tube Boilers, Superheaters, Water Walls, Economizers, Air Heaters, Feed Water Heaters, Evaporators, Condenser Tubes, Pumps, Waste Heat Boilers, Vacuum Refrigeration Systems	165 Broadway, New York	xxi
G			
General Electric	Electric Machinery of All Classes	Schenectady, N. Y.	xxiii
Gibbs & Cox, Inc.	Naval Architects and Engineers	New York, N. Y.	vi
Griscom-Russell Co.	Distilling Plants, Feed Water Heaters	285 Madison Ave., New York	vi
I			
International Nickel Co.	Producers of Nickel	67 Wall St., New York, N. Y.	v
International Telephone and Telegraph Corp.	Communications — Research — Manufacturing	67 Broad St., New York, N. Y.	xxvii
J			
Johns-Manville	Insulation, Refractory Cements, Packings, Brake Linings, Asbestos Ebony for Switch and Panel Boards, Waterproofing Transite Asbestos Sheets, Transite Pipe, Roofing and Shingles, Flooring, Insulating Board Products	22 East 40th St., New York City	viii
K			
Kingsbury Machine Works, Inc.	Thrust Bearings, Journal Bearings, Thrust Meters	Frankford, Philadelphia, Pa.	xv
L			
Lanman Engraving Co.	Photo Engravers	612 L St., N. W., Washington, D. C.	iv
Lidgerwood Industries, Inc.	Steering and Deck Machinery	7 Dey Street, N. Y. 7, N. Y.	xix
M			
Moffitt, Lucian Q., Inc.	Cutless Bearings for Stern Tubes and Struts	Akron, Ohio	iii
N			
Newport News Shipbuilding & Drydock Co.	Naval and Merchant Vessels	Newport News, Va.	ix
New York Shipbuilding Corporation	Shipbuilders	Camden, N. J.	xi

Name.	Manufacturers of or dealers in	Post office address.	Page
R			
Radio Corporation of America: Govt. Equip. Section	Radio Equipment	Camden, N. J.	xviii
Raytheon Mfg. Co.	Contractors to the Armed Services	Waltham 54, Mass.	xv
S			
Seaporcel Metals, Inc.	Ceramic Coated Products	28-20 Borden Avenue, Long Island City, N. Y.	iii
Selby, Battersby & Co.	Deck Covering for Ships	5220 Whitby Avenue, Philadelphia 43, Pa.	xxx
Sperry Gyroscope Co., Inc.	Radar, Loran, Gyro-Pilots, Gyro-Compasses, Electric and Hydraulic Steering Equipments, Magnetic Compass Pilot, Rudder Angle Indicator, Naval Fire Control Instruments, Aircraft Gyropilots, Flight Instruments	Great Neck, N. Y.	vii
T			
Terry Steam Turbine Co.	Steam Turbines	Hartford, Conn.	xxviii
U			
U. S. Naval Institute	U. S. Naval Institute Proceedings	Annapolis, Md.	xxv
W			
Ward Leonard Electric Co.	Electric Control Devices	Mount Vernon, New York	xxviii
Westinghouse Electric & Mfg. Co.	Marine Steam and Electrical Equipment	East Pittsburgh, Pa.	xvi
Worthington Pump & Machinery Corp.	Pumps, Condensing Apparatus, Diesel Oil Engines, Gas Engines, Fluid Meters, Compressors, Feed Water Heaters	Harrison, N. J.	xxii

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Welding the seams of Monel sea water storage and treatment tank. (They'll be as corrosion resistant as the metal itself.) Port hole on top permits observation of sulfuric acid addition and aeration in first step of test to determine radio-active carbon content (and thus the age and movement) of sea water drawn up from the ocean depths.

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That's the problem scientists are trying to solve. And here's how Monel® is helping them solve it.

Aboard the research vessel "Atlantis," which is operated by the Woods Hole Oceanographic Institution, they haul samples of sea water from the ocean's depths.

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Originally, it was thought that steel could be used for this tank on the "Atlantis." But rapid corrosion put an end to that idea. Rudman & Scofield, Inc., fabricators of many items of fine yachting equipment, were consulted about the problem. They knew from experience that the special corrosion resistance needed is found in Seagoin' Monel.

Whenever it's a problem of material for tanks, whether for standard uses such as fuel or water storage, or the out-of-the-ordinary applications such as this special piece of equipment on the "Atlantis," designers, builders, owners and operators specify Monel.

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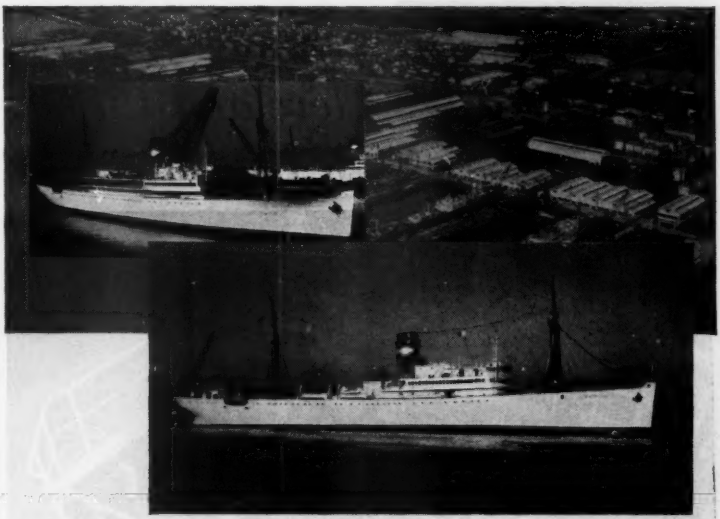

Above . . . the Veragua ties up for alterations. At right . . . a sister ship, the Quirigua, after conversion.

Another example of

Fast Conversion

United Fruit Ships
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Look at the Quirigua... the first of four United Fruit Company vessels to undergo extensive alterations.

The visible result is the removal of the super-structure, aft of her stack. The efficient conversion of the Quirigua, and her three sister ships, demonstrates how the experienced teamwork of Newport News personnel cuts down costly lay-up time.

Newport News has the facilities, as well as the skilled organization, to make alterations in the shortest possible time. We invite your inquiries.

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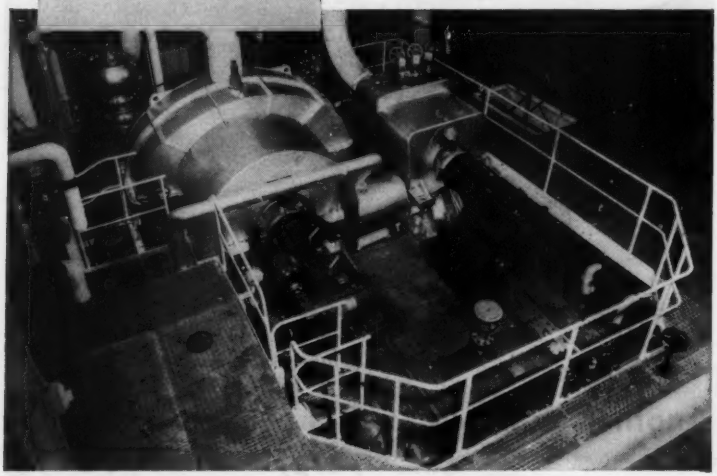

This De Laval 7,700 shp main propulsion unit provides dependable, efficient power for the steamer *Edward B. Greene*, the new flagship of The Cleveland-Cliffs Iron Company fleet.

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For decades, fleet operators have counted on precision-made De Laval marine equipment to power passenger and cargo ships, tankers, ore carriers and many other types of vessels.

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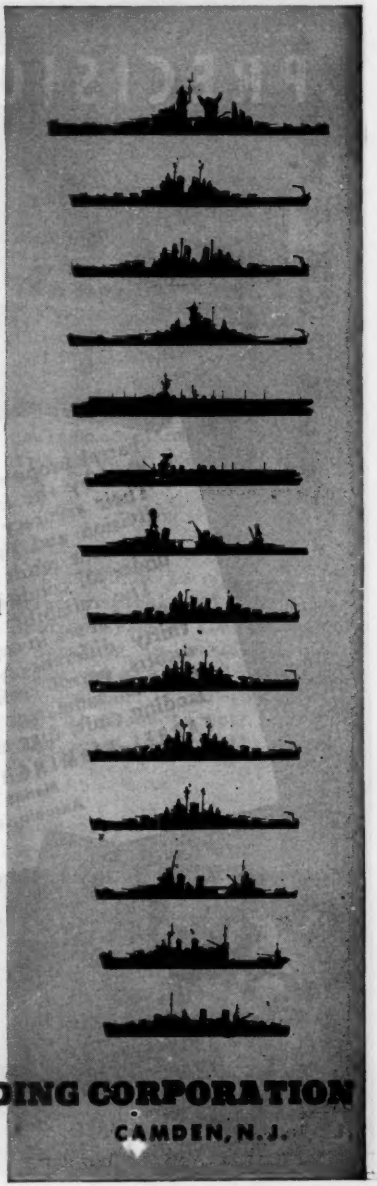

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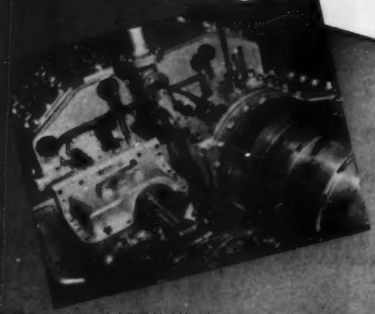

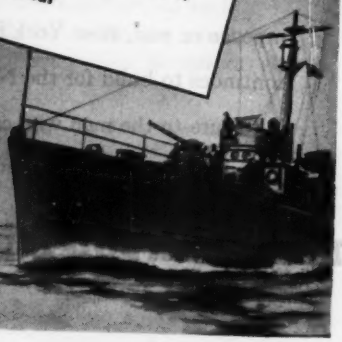

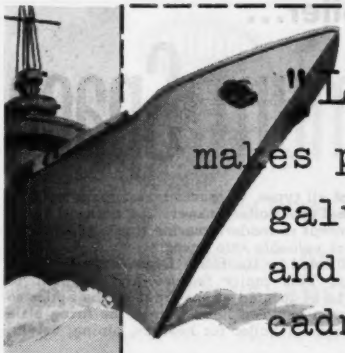

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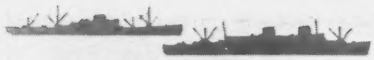
Simplified design of B&W's Drum-Type Boiler affords numerous other time- and cost-saving advantages which substantially benefit everyone interested in marine progress. These include light weight . . . greater freedom in piping design . . . initial cost savings . . . easier, faster erection . . . improved boiler performance . . . lower operating and maintenance costs . . . increased accessibility for quicker, easier inspections and repairs . . . and improved working conditions. The Babcock & Wilcox Company, Boiler Division, 161 East 42nd Street, New York 17, N. Y.



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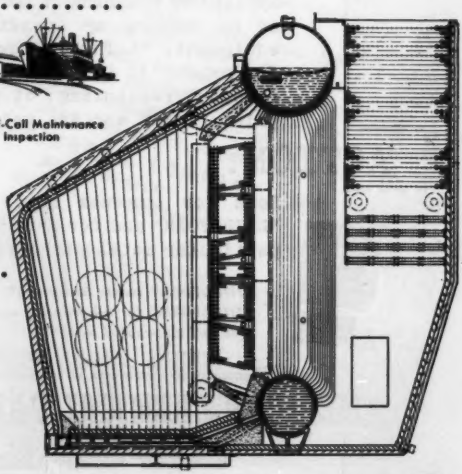

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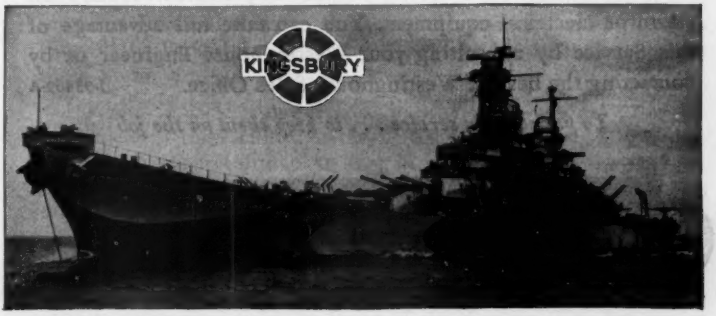

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JOURNAL
OF
THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

VOL. 65. MAY 1953. No. 2

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SECRETARY'S NOTES

THE 1953 BANQUET

The Society on 1 May held another successful annual banquet at the Statler Hotel in Washington, D. C.

Preceding the dinner some thirty-odd receptions were held by friends of the Society — industrial companies, each of whom has many Society members among its officers and engineers. These scattered informal parties have always been a very attractive feature of the banquet evening and the Society is much indebted to these hosts.

Again in 1953 a new record in attendance was set. A rearrangement of the facilities of the Statler provided a slightly higher capacity than heretofore. At least in part, credit for the new arrangement goes to the Washington Fire Marshal who objected to the hazards of the previous seating. Use of the Federal room instead of the corridors, which was the result, was made possible only by the generosity of the Westinghouse Electric Corporation and the General Electric Company, each of whom surrendered certain contractual rights in favor of the Society. For the second

year those attending who could not be placed in the best seats had the advantage of a television reproduction of the speaker's table through the courtesy of the Radio Corporation of America.

The dinner and the program were presided over by Rear Admiral Homer N. Wallin, U.S.N., the President of the Society. Past President Vice Admiral Earle W. Mills, U.S.N., retired, President and Chairman of the Board of The Foster Wheeler Corporation officiated as Toastmaster.

Mr. Gwilym A. Price, President, Westinghouse Electric Corporation, was the principal and only formal speaker. His very stirring address entitled "The World's First Line of Defense" was a privilege to hear. For the benefit of those members who were unable to attend the banquet the privilege of reading Mr. Price's speech is extended by the reprint of it which is being distributed with this issue of the JOURNAL.

OLDER MEMBERS

Occasionally the Secretary has the pleasure of reading letters from members who entered the naval engineering profession more than half a century ago. Two such letters are reprinted below so that other members may share the Secretary's pleasure.

109 Douglas St.,
San Francisco 14, Calif.
1/10 1953

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Gentlemen:

Enclosed find check for $7.50 for dues for present year. Please return me the receipt for my files and oblige.

Last January I sent increased dues with request that you send me a lapel button which I never received.

My whole life has been connected with engineering work cost.

I was Acting First Engr. on the *U.S.S. Yankee* in the Santiago campaign. Had charge of building *U.S.S. Maui* at iron works, San Francisco, and of the turbine construction at Pittsburgh, Pa., in 1916. Finished construction at Union Iron Works and took the ship to sea (was attached to Cruiser and Transport Force, Atlantic Fleet), Admiral Glover, 1917 to September, 1919.

I fear my excuses must be offered for my writing due to operation on eyes.

On return from first World War I was appointed efficiency engineer of the Matson Nav. Co., but had to leave 1921 due to

illness acquired in war and was retired to Emergency Officers' Retired List only to lose same due to the Economy Act, 1932 at start of the Roosevelt Dynasty. Admiral C. W. Dyson was a dear friend of mine, also 1918 Fleet Engr. Capt. E. D. Almy.

I have enjoyed being a member of the American Society of Naval Engineers and have many of my old-time friends and was sponsored for this membership by Admiral Hook. For two years now I have been confined to my home.

My three-score and ten are long since passed (born Oct. 24, 1871), and my father died from wounds received at Antietam in September '62; wounded also at Bull Run.

Admiral Francis W. Dickins was a friend of my boyhood and Admiral Walter Crosley a schoolmate.

Hoping I haven't bored you, closing, very truly yours,

ALEXANDER RYAN.

P.S.: I might mention that Admiral Koots was in charge of the fitting out of the *Jeanette* for the De Long Arctic trip for Admiral Melville.

February 16, 1953.

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

WASHINGTON, D. C.

Sir: Attention, Capt. J. E. Hamilton, Treasurer!

Thank you very kindly for your letter of February 10 inst.

I appreciate your generous offer; it's more than I deserve, but I shall be governed by your desire.

Have completed over 53 years of designing, development and engineering work on marine engines, boilers and their accessories. Also, 23 years' service in the Naval Reserve, four years of which was spent in World War No. 1 on active duty (engineering duty only).

I organized the Naval Reserve at Erie in 1911, and when war was declared in April, 1917, entrained with 130 men for Philadelphia, Pa. Old *Wolverine* was our training ship.

Thank you very kindly for placing name on your Exchange List, I am, with kind regards, yours sincerely,

LANDIS E. ISAACS.

THE FUTURE OF THE SOCIETY

Evidence that someone has actually read the Secretary's Notes is always welcome. The letter below, which was received from Lieutenant William J. Waylett, U.S.N.R., is an example of such evidence. This letter bears on the question which was raised in the February issue of the JOURNAL. Comment from others on Mr. Waylett's letter or on the general subject is desired.

March 5,1953.

Captain J. E. Hamilton, U.S.N., Ret.,

Secretary-Treasurer,

American Society of Naval Engineers, Inc.,

605 F Street, N. W.,

Washington 4, D. C.

Dear Sir:

In a note in the February issue of the JOURNAL there was cited the opinion of the Council regarding the proposal of some members of the Society that an intensive membership drive, aimed at creating a bigger and better Society, be undertaken. The Council rejected the premise that a better Society could be created, and pointed out that the Society is experiencing steady growth, without detriment to the quality of membership. Comment was requested from members.

The Council is absolutely correct in their position. If a professional society is to maintain high standards of membership, it must make that membership a thing to be desired. It has been my experience, in participating in membership drives in other associations, that while you can increase your membership in this manner, only a small portion of that new membership will prove of lasting value. For the most part these new members, drummed in by the enthusiasm of their friends, are not really interested and will drop out of the Society after a year or two of membership.

Only a man who has pride of profession, who recognizes the value of professional association, and who is interested in his own professional welfare and advancement will seek membership of his own accord. This type of membership is usually of high quality. No membership drive is necessary to induce him to join the Society. He does so because he wants to belong and takes pride in that membership.

Each issue of the JOURNAL contains several pages of new members, which to me indicates a healthy condition of membership. These people have become members of their own choosing and

this would indicate that the Society and the JOURNAL, by their quality, are attracting new membership of the type which is more desirable and more lasting. This tends to maintain that quality while at the same time providing new blood and steady growth.

Examination of the Society's financial statement, in the same issue of the JOURNAL, reveals that the Society's finances are in good shape, that it is well managed, and that there is no need to initiate a membership drive for the sake of the increased revenue that would result. The good financial status of the Society, coupled with the desire to maintain quality of membership, are sufficient reasons to justify the Council's stand in rejecting the proposed membership drive. I do not believe that we stand to gain in either respect by undertaking any major membership drive at this time.

Sincerely yours,

WILLIAM J. WAYLETT,
Lieutenant, U.S.N.R.

AN "ACTIVE" MEMBER

For the second time, Captain Carl J. Lamb, U.S.N.R., has offered a year's membership in the Society to the Naval R.O.T.C. senior at Rice Institute, Houston, Texas, who is commissioned as an ensign in the Naval Reserve upon graduation and who stands first in the Naval R.O.T.C. unit in mechanical engineering.

Among Captain Lamb's other contributions to the Society are frequent articles for publication and the recruitment of many new members.

EDITORIAL POLICY

Although letters of criticism or of approbation are very rare, the Editor does occasionally encounter some of these things orally. The latest was a complaint that too many articles by one author were published. A view of the Table of Contents may help to explain what was meant by this critic. It was a new complaint to this Editor. It was our thought that, although we are avid for first works of value, an experienced and frequent writer is never rejected by any publication for the sole reason that he is experienced and has written frequently before. There are really only four requirements for an article for the JOURNAL. Those are:

1. The article must be submitted. We have long suspected that more possible authors stumble on this point than on any of the others.

2. The article must have some pertinence to Naval Engineering in the 1953 connotation of the profession.

3. It must be deemed to have merit.

4. There must be space in the JOURNAL within budgeted limitations.

The Editor may be treating this criticism incorrectly. He would be glad to hear from any member in the premises, pro or con.

PRODUCTION ENGINEERING, COMMUNIST POTENTIAL

(It is a mistake to underrate Soviet Industry)

CAPTAIN R. E. W. HARRISON, USNR

THE AUTHOR

was born in Manchester, England, in 1893. Educated Manchester College of Technology. With Royal Engineers, British Army 1914-1919, Egypt, Gallipoli, Sinia, France, Belgium. Industrial Engineering experience includes special apprenticeship and supervisory positions with Churchill Machine Tool Company, England, in the building, design and engineering selling of precision grinding machinery; in 1926 as Director of Engineering, Cincinnati Grinders, Cincinnati Milling Machine Company; 1934 Chief, Machinery Division, U. S. Department of Commerce; 1935 Vice-President Chambersburg Engineering Company; in War II, on staff of Assistant Secretary U. S. Navy, and later as Special Assistant to the Under-Secretary. Registered Mechanical Engineer in Ohio, New York, Pennsylvania, Maryland and District of Columbia. Fellow, ASME and Royal Society of Arts; Member other Engineering Societies in USA and Europe. Present Duty, Industrial Engineer, Field Activities, BuShips.

The thought persists that a recounting of experiences gained in contacts with the Production Engineers of the Soviet Union, could have useful significance at this time. The machine tool engineer, in his methods of doing business, is much akin to the custom tailor with a wide variety of customers. Each problem has a distinctive individuality, and each solution must be tailored to satisfy the needs of that particular problem.

In a series of business contacts dating back to 1919, the author has accumulated the experiences recounted below, and offers them for perusal with this thought in mind.

An estimate of the Soviet situation may be colored by the estimator's low evaluation of the intellectual worth of the faces we see on the pictures. Low brows, puffy cheeks, glazed eyeballs, hard looks, and a generally sullen expression reminiscent of that of a frustrated truck driver, naturally generate a low estimate of intellectual capacity.

Herein lies the catch. These are the politicos, the front men, the top policy makers, the people in the news, the standees on the slab in the Red Square for the annual May Day parade. They may be the triggermen, but they are certainly not the power behind the gun. They are, in fact, "the frocks," as one

succinct writer recently described them, and for the moment our business is not with them, but with the supporting technicians, the professionals whose skill, endurance, and productivity the politicos live and plan on.

The story starts in 1912. At that time, the author was a minor official in an English machine tool manufacturing plant with an annexed business specializing in the making of high grade milling cutters, hobs, special drills, gauges and other fine tools. An appreciative customer was the Russian Romanoff Government. Purchases were large enough money-wise to be interesting, the relationship was pleasant, payment was prompt, and the inspector who inspected, prior to acceptance, the finished goods was a scholar and a gentleman; as his business card stated, a Lieutenant in the Russian Imperial Army. It was always a pleasure to do business with Lieutenant Pavloff.

It was inevitable that August 3, 1914 (Mobilization Day) should come around, and on this day, the author donned field khaki, and was destined to wear it until well into the Spring of 1919. In the bustle of mobilization into a field engineering company, Lieutenant Pavloff and his special cutting tools were momentarily forgotten, but later hastily recalled, when, on a final visit to the Company office on the day prior to shipping out to Egypt, Lieutenant Pavloff was again encountered. This time he was inspecting what turned out to be the last batch of tools made for Imperial Russia by this particular company.

There was, however, a difference. Pavloff was in uniform, and his shiny riding boots, smart dress uniform and rakish shako made the author's field khaki look drab, indeed, beside such splendor. The greetings and parting were cordial. Some other member of the Concern, not destined for military service, was handling the customer's inspector, and we went on our respective ways. Pavloff was recalled to Russia on the same day the author sailed for the Near East.

Continuous field service in many theatres of War, frequently in contact with the enemy, left little time for contemplation of the problems of the machine tool industry or its associated business of making the cutting tools which the machine tools utilized.

An incident, or something perhaps better described as a condition, occurring on the onset of the Gallipoli Campaign, provided much food for thought. It is, of course, now ancient history that the Naval attack on the Narrows failed because of inadequate minesweeping by the attacking force, but from the mere soldier's viewpoint, the enemy guns which resisted our landing proved, on examination, to have been a Mr. Armstrong-Whitworth's best, projecting greetings from Messrs. Vickers. The memories of these two concerns produced a strange nostalgia. The time, however, was slight; because it became imperative to go to earth to avoid even more insistent greetings from brother Krupp's representatives barking their welcome from Chanak over the Narrows.

It will be recalled that in those days, our Greek friends possessed two submarines of British make, and naturally the British staff, having been incompletely briefed on the subject of enemy mines, were also somewhat torpedo sensitive. The not known or undisclosed whereabouts of the Greek submarines was a constant source of anxiety which, in short order, became unbearable to the point where the Greeks got a peremptory order to either produce them or have them sunk on sight.

In due course, all things come to an end, and released in early 1919, as a pivotal man, allegedly influential in the creation of enlarged employment facilities in England, the writer was returned to the bosom of his company in Febru-

ary 1919, with the blessing of the Army and the fervent hope of the company management that many months in the field would not have ruined the will to productiveness in the re-inductee.

It had not; the old routine was resumed, in a position of higher responsibility. It was with somewhat of a shock, when traversing one of the machine shops one day, to be hailed by a long forgotten voice coming from an individual whose outward shabbiness was almost phenomenal, and whose unkempt appearance was almost repelling. Yes, it was Pavloff again, but this time, instead of a cheery greeting in the former clipped military terms, it was, "Hello, comrade."

Pavloff was on the same job for the Soviets as that which he exercised for the Imperial Russian Government. He had, of economic necessity (I never inquired about his loyalty convictions) taken employment under the Soviet Government, and they, wise people that they were, put him to work on that which he had known most intimately, i.e., the inspection of purchased metal cutting tools.

The meeting was momentous in one way. Pavloff tipped the author off to forthcoming heavy purchases of machine tools of the types manufactured by the author's company, and prompt action resulted in a phenomenally large contract under extremely favorable terms of payment. It was notable at that time, however, that the Commissar, who handled the transaction in ARCOS (Soviet Headquarters), London, made known in no uncertain terms his resentment at the way in which the information had reached us, and Pavloff disappeared from the scene. Whatever the penalty may have been for his lack of discretion is not known, however, he was never seen again by his English friends.

BRITISH MACHINE TOOLS FOR THE SOVIET UNION

A prompt contract for precision grinding machinery was the first of many. The business was more than welcome, prices were profitable, payments were prompt, and inspection was usually waived. As was customary, this waiving of inspection automatically imposed a moral obligation on the manufacturer which automatically protected the buyer against the supplying of defective equipment. In fact, the manufacturer bent over backwards, if not in appreciation of the waiving of inspection, at least in the hope and belief that the good quality of work which he produced would lead to a continuance of the favorable terms of payment, and freedom from an onerous inspection of machinery.

Despite all of this, there were uneasy feelings on the part of the manufacturer. The quantities of tools were so vast, the amateurishness of the queries which were leveled in regard to how to use the equipment, and the crudeness of the buyers augured ill for the continued usefulness of the machinery after it was delivered, and it was with no surprise that the author learned from another official of the company, who had been invited to Russia for a tour of factory inspections, that much of the product we were so proud of, laid out in the open, rusting and deteriorating rapidly, in broken packing cases.

The business continued with but relatively slight slackening up to the period of the infamous Zinovief letter*—and

* Zinovief letter. The Zinovief letter was reputedly the letter of instruction from the Soviet to the communist cells in the British Army, instructing the cells in the art of sabotage. It was the uncovering of this letter and its publication, just prior to a general election, which swung the popular vote in a landslide from the Socialists to the Conservatives.

by 1926 was in full swing again under slightly less favorable terms of payment but a much more asute appreciation by the buyers, of productive values. By buying the best and most expensive production machinery of its kind, the relatively newly born Soviet Union was displaying, even at that early date, a keen perception in productive values, which manifested itself in the purchase of large quantities of the very highest grade production machinery.

SUPPLIES FROM THE UNITED STATES

It was about this time that the author transferred his residence on a permanent basis to the U.S.A., joining the staff of the largest machine tool manufacturer in the U.S., as Director of Engineering, with primary responsibilities for the creation of engineering design, but secondarily, as is inevitably the case in the U.S.A., with an enduring responsibility for the generation of profitable sales.

A natural query by the author, raised at an early Company Board Meeting, was "Why no business from the Soviets?" The answer was blunt and uncompromising. The Soviets enjoyed no credit with the author's new organization, but if they wanted to come in on a cash and carry basis, that was all right.

Again, here was a company making the finest equipment of its kind produced in the world. Equipment indispensable for the furtherance of a prosperous internal economy and equally indispensable for the creation of arms. It was not long before the author was approached by the Amtorg organization in New York, and the resulting introductions caused the hitherto existing credit barriers to be satisfactorily disposed of; the show was on again.

Substantial order, after substantial order, with favorable terms, prompt payment, light inspection and cordial business relationships were generated. Purchases were large and in quantity ranked with those made by the largest American Corporations, such as General Motors, and the big Electrical Equipment Manufacturing Corporations, but this time the enquiring probe was getting sharper and longer, and it was abundantly evident that the new Soviet Republic was rapidly developing a keen appreciation of the superior merits of American manufacturing techniques. His questions were more searching, his perception in determining the relative merits of competing techniques was nearly always flawless; in other words the young Republic was taking not a leaf, but a whole swatch of chapters out of the industrial guide book of the old Republic.

In the early days of Soviet trade, the negotiators were Commissars, and quite frequently those who determined the specifications were military men. All had tough personalities, and while occasionally there popped up an obvious intellectual, he was always in a subordinate position and amongst a group of negotiators, was invariably the watched, rather than one of the watchers.

The author well recalls how, in a company washroom, prior to lunch in the cloistered dining room of a conservative old English concern, the Soviet Admiral removed his coat to facilitate his ablutions, and thereupon disclosed something pretty close to a .45 caliber automatic in his hip pocket. He was a little startled when the writer surreptiously removed his artillery, found it loaded and cocked with the safety on, and then suggested to the Admiral that he participate in a little pistol practice in the adjoining lot. The incident, trivial in itself, was indicative, as always, of an attitude of mind.

Through the succeeding years up to the outbreak of World War II, the

catalogue of Soviet acquisition of American manufacturing technique is replete in its record of thoroughness, objectivity and technical competence. There were, of course, blunderers who stepped in with impractical demands, but the overall picture was, and still is, overwhelmingly convincing.

The Soviets were on the industrial march, and as is always the case, when rapid results are forthcoming, the men who made the penetration were much more interesting than the machinery. These men were a new crop—practically all of them business-like technicians—highly educated in the higher branches of the engineering profession.

There was one hiatus in talent when the capable Jewish buyers were ousted from Amtorg, and replaced by a group of cagey, cautious amateurs, but these, in turn, soon gave way to the current crop of technical production men, well capable of extracting from the machinery they bought from the U.S., its ultimate in productivity.

Inspection by Russian engineers of machinery bought under contract by Amtorg presented around this time many difficulties, whereas in the early days of Soviet business, inspections had been light, and it was obvious that reliance was, of necessity, placed on the honor of the machinery building concern, this attitude and policy gradually changed, until inspections became onerous, and the slightest argument between builder and inspector immediately brought forth the Slazenger handbook of machine tool tests and standards, together with all their impractical implications from the American viewpoint.

So intense became the fight between inspection and production that threatened law suits, based on non-acceptance of contracted for machinery, occurred by the dozen, and it was not until intervention by the highest Soviet authorities had been secured that the situation was eased to the point where shipments could be continued. The explanation, as is always the case in the last analysis, turned out to be simple in the extreme. The inspector was on a spot, so three martinis decreed, and if the machinery he accepted failed to perform in accordance with some production engineer's concept in the U.S.S.R., it was curtains for the inspector—and quick.

By and large, the Slavish customers were alert, capable engineers, basically well grounded in the facts of engineering life. Their seeming aberrations of judgment obviously mirrored the restraining discipline to which they were subjected; this discipline showing through the cloth at every turn in their consistent refusal of even the simplest courtesies and conveniences, normally offered by an American business concern, to even its most insignificant customers.

Not always, however, is this rigid abstinence practiced. When the Soviet engineer seeks information, his hospitality is lavish and his capacity for strong medicine apparently unlimited.

An encounter of this kind with the author as the guinea pig, by strange turn of fortune, reversed the rules. On the morning in question, prior to the luncheon engagement, a large dose of mineral oil was imbibed in an effort to counteract New York's well chemicked water. Over the vodka cups this accidental medicine proved its worth. The interrogator, cup for cup, became the interrogated, and his languor so pronounced, that half-way through the luncheon, with head rested on his own hands, he slept, temporarily at least, at peace with the world.

Concurrently during these years, many of the best production technicians in the U.S. were induced to go to Russia, ostensibly to sell, but primarily to teach the ways of American mass production. Examples are numerous where success grew out of their efforts; one of the

most outstanding being the creation of the new tractor factory at Chulyabinsk, close to the Urals, where a former superintendent of the leading tractor manufacturer in the U.S. put in three years of grueling, hard work in the creation of a thoroughly modern tractor company.

Just how well this man and his Soviet associates built has been recently testified to in about the only way which now can be expected. A couple of heavy duty tractors captured from the Reds on the Korean front and shipped to the U.S. were stripped and critically examined by the engineers of the manufacturer who fathered the original design. Net result—a freely stated evaluation which appraised the Soviet tractor at higher horsepower than its American parent, and with several features of superiority in minor design.

FORGING MACHINERY

With the advent of 1935 and the recovery from the creeping paralysis of the big depression, the Soviets were again in the U.S. market in a big way, offering business as usual at attractive terms and forever seeking along with the purchase order for the machinery, commitments in regard to manufacturing techniques.

Technicians from controlling jobs in Soviet factories came to the U.S. in droves, keen, perceptive men with flawless technical education, and the drive to secure knowledge which only the spur of Sovietism can instill in men whose families are still in the homeland. There was but a slight lull in the process of acquirement when the U.S. State Department decreed the need for separation of diplomatic and business channels, but soon the swing was on again, this time restored to the more normal channels of business negotiation. The venue, New York, made but little difference. A rose by any other name!!!

An incident, small in itself, but significant of the kind of iron discipline prevailing in the Soviet, occurred about the time when the Russian appreciation for American forging machinery became manifest. Amtorg decided to send a VIP—no less than Kagonovitch—to imbibe the technical merits and negotiate the purchase of machinery destined to build up Russian aviation industry.

The start was a telephone call from New York, announcing the forthcoming visitation at 9:00 o'clock the following day, by the great man, the plan being that he would be met at the plant by a group of his technicians.

Kagonovitch came by rail, arriving an hour early, i.e., at 8:00 o'clock rather than 9:00—refused the hospitality of the office staff for a comfortable seat in a warm office, and paced the streets of the small Pennsylvania town in high disgust, because there was no officer of the Company available to meet him, 9:00 A.M. being the normal time of entry and also the time for the appointment. A brief exchange of the usual courtesies soon disposed of this small matter, but immediately a larger and more important crisis loomed.

Where were the technicians? The night had been foul—high winds, high water, and a continuous downpour of pelting rain. The technicians, poor devils, seven of them, had decided to come by road in one car. The meeting with their boss was dramatic. The place—the foundry. Our tour of inspection of the plant had already started when the missing technicians showed up.

The men lined up, and their headman made his stammering excuse in Russian. Somehow the explanation failed to mollify Kagonovitch, for his reproof was short and sharp. Completely non-understandable to the Ameri-

cans, but apparently of strong medicine, because his seven listeners, to a man, turned the color of a very early, pale, green apple. It was obvious that their day had been spoilt. This was equally obviously industrial discipline—Soviet style.

While machine tools, as such, i.e., tools which cut up basic metals into usable shapes, are a prime necessity in any program aimed at peace or war, no element in the hierarchy of tooling occupies quite the same vitally key position as that occupied by forging machinery.

Forging machinery is of the very essence. The forging press, the drop hammer, and certainly the blacksmith hammer, as well as the trimming press, all basic tools in the manufacture of a pair of scissors, a surgeon's scalpel, knives, forks and spoons, screw-drivers, and monkey wrenches, will merely, as the result of the changing of a set of dies, make, with equal facility, rifle receivers, rifle bolts, machine gun components, breech blocks for cannon, bayonets and projectiles. In other words, forging machinery is of the very essence of both peacetime and wartime fabrication.

In many ways it is a strong tribute to the astuteness of the Russians that, after searching surveys of the forging resources of the world, they settled on the U.S. as the best place in which to find the right answers. This statement is not based on any hollow claim to accomplishment. For instance, in the U.S. a hammer team, or a forging press team, in the forge plants of the big automobile industries, and the manufacturers who serve them, make an average of 90 Chevrolet size crankshafts per hour, for eight hours a day, or if need be for sixteen hours a day, two-shift operation. In England, the rate of production on the same size, type, and design of crankshaft, is less than half this number, even when the British shops are supplied with the best American equipment. In France, similar production is around 50 per hour in a first class plant like the Renault Forge Plant. In Germany, the best they could do with German hammers was no more than 25 crankshafts per hour.

What about the Russians in this highly competitive field of making good forgings at the cheapest price? The Russians make a consistent 85 cranks per hour, this being the crankshaft for the Zis car, a 6-cylinder job with an engine very similar to the Chevrolet.

So it goes on, all down the line. When it comes to making forgings which are of the very essence of war materiel, the Russians can practically match the U.S. production, production unit for production unit, and their rate of production is much superior to that of our worthy Allies.

Another fact, which those who consider the Russians incompetent, should forever keep in mind, is that in their pre-World War II purchases, the vast quantities of equipment they got under lend-lease, and their very heavy post-war purchases of forging equipment, they have equipped their forge plants with the most modern tools, and the quantities acquired cannot help but place them, insofar as units in service are concerned very close to the U.S. capacity. The foregoing does not take into account the Russian inroads into that German field, where German techniques really shine, i.e., the German heavy forging press industry.

It is a reasonably reliable estimate that the Russians have in use today between eight and ten of the largest size heavy forging presses in the 18,000/50,000 ton capacity range. Here is a field but lately appreciated in the U.S.A., hence today we are confronted with the necessity for a hurry-up program to enable us to catch up with our Muscovite friends, not only in the designing and fabrication of these presses,

but we have to train crews to use them and get the best out of them.

There always has existed an undeniable ingenuity in the American solution of the production problem, but sight should never be lost of the fact that our big solutions come mainly from the urge of economic gain, i.e., profit in industry, this being of the essence of our competitive, capitalistic system which yields profits to the enterprising, and economic death to the dilatory.

True, it is that under the stimulus of war we produced the first real manifestations of nuclear power, and many other valuable peacetime utilities, owe their birth to wartime necessities, but by and large the American high standard of living owes its inception and continued growth to the economic system, and not to war stimulation.

The motivation which makes our potential enemies tick is entirely different. They seek territorial expansion. They also seek with fanatical zeal the spreading, on a world-wide basis, of their peculiar ideology. This and the five percent of the population who control the other ninety-five percent, predicate better than eighty percent of the country's resources to the war making potential. The implications from the U.S. viewpoint are, to state it mildly, terrific.

INDUSTRIAL DISCIPLINE

While it is the intent of the author in presenting this thesis to limit the discussion to production technology, the thought would not be complete without fleeting reference to the subject of industrial discipline.

Industrial discipline, U.S. variety, is in essence very largely self-imposed by the individual. True, there are ground rules which must be observed by everyone from the president to the man who sweeps the floor, but by and large, the efficient utilization of America's production machinery with its vast potential, is realized because everyone continually seeks access to a higher standard of living, and the channel through which this is achieved is the monetary one. There can be no argument that the system pays off handsomely. The statistics bear it out irrefutedly, and this is no place, nor is there necessity at this time, to repeat them.

Industrial discipline in the Soviets, as observed by this writer, is another matter. It is rigid where it can be enforced, and no effort by the Commissars is spared in this direction. However, it is readily observable that even the most docile people in course of time become inured to terror, and the job of policing them becomes disproportionately onerous.

If we all, as we must, accept the philosophy that our net gain is that which we retain after the inevitable expenses and obligations have been disposed of, then the free enterprise system shows up handsomely as a business proposition. The spiritual gains and satisfactions which accompany a superior achievement can be regarded as an extra dividend. This author's observation of the Russian industrialists indicates that the Russian system produces neither a rapid advance in the standard of living, nor a dividend for the worker, spiritual or otherwise.

A pertinent question at this time could well be then, what makes these people tick, and the tabulation of the reply could well be as follows:

1. Acceptable production accomplishment can usually be depended upon to bring forth a small reward, a little extra food, a little better home, maybe some extra clothing, and on the basis that two bits is a

lot of money to a man who has no money, this meager reward can pay off.

2. Terror of violent reprisal from the powers-that-be is a potent driver, especially where the whole family is made to suffer for the alleged sins of one member.
3. In many ways the industrial resources of the country are well heeled. The basis of all modern industrial prosperity is machine tools, and the Russians have a lot, which they acquired from Western Europe and the United States, and they have made a lot more in the form of copies of that which they have bought. This undoubtedly is the most solid element in their industrial foundation when supported by a corps of capable production technicians.
4. The Soviets have the benefit of the services of many accomplished German technicians and scientists.

All manufacturing production technology must, of course, be predicated on an adequate supply of raw materials, plus an adequate plant equipment and technique for the conversion of these raw materials into the semi-finished raw state which permits the tools of industry to go to work on them. Accurate figures are lacking regarding the Soviet supply of raw materials, but their activities in world markets, plus the garbled reports, all seem to indicate that coal is being mined, water power is being developed, iron is being mined in vast and rapidly increasing quantities. Probably no vast country in the whole world was so geologically surveyed as the territory of the Soviet Union just prior to World War II.

MANPOWER UTILIZATION

An over-abundance of manpower, history says, irrefutably leads to its wasteful utilization; however, be that as it may, the fact remains that the finest natural resources, the most adequate supplies of blast furnaces, machine tools and forging equipment, all add up to zero if the manpower to put these resources to work lacks inherent ability and skillful direction. Such indications as we have, tend to prove that the Soviets are learning rapidly, how to best utilize their vast plant, and it is repeated that this article is dedicated to the thought that our planners, i.e., the U.S. and her Allies, should not predicate their plans on the assumption that the competition lacks adequate resources, and is in any way industrially incompetent.

The danger from the Western Allies' viewpoint lies in the possibility of a wasteful use of the present and growing over-abundance of manpower. Again, history states that no nation ever built up large armed forces, particularly when this is done at the cruel expense of the standard of living of the populace as a whole, without having a military objective in mind. Big armies, or rather over-large armed forces, and war go together pretty much as bacon and eggs, or scotch and soda. In this thought lies the implication, and very obvious danger to the Peace.

For this author, the circle has been completed. In 1926, motivated solely by a desire for more trade, a resolution of his Company Board granting certain credit facilities, made this trade possible. Almost twenty years to the day later, again at this author's instigation, a Board of an equally important company cut off its trade, in the belief that it was suicidal to sell to a potential enemy the wherewithal to make that enemy stronger.

CONCLUSION

The basic illusion which prompts and motivates so many otherwise straight-thinking people amongst the Western Allies is that communism is a form of politics. This, despite the fact that it has been repeatedly and irrevocably proven that communism and politics as we understand them are as the poles apart. Webster makes this abundantly clear; however, it should be noted that other encyclopedia authorities put a very much milder interpretation on communism than that which Webster offers. The basic divergence is in the field of ethics. The Marxian philosophy embraces the thought that the end justifies the means, whereas in politics, as we understand them, good ethics are essential, and politics under this definition is an honorable profession.

Obviously, it has been the Soviet's policy, and presumably is still the policy, to gain by all ends attainable, knowledge of the production techniques of the Western Allies, and many significant stories could be told of the lengths the Soviet agents have gone to in carrying out their commercial objectives; however, in this author's opinion, the great manufacturers of the U.S. and our Western Allies, more or less unwittingly, have, in the normal practices of their commercial art, traded to the potential enemy the techniques which are of the essence of our industrial strength. As a salve for the conscience for so doing, the statement has been many times heard that—"what if the Kremlin does get really belligerent some day, the cluks could not make use of that which we have given them, or rather sold to them."

The mission of this article is to explode for all time this one thought, i.e., that the vast majority of Russian technicians are cluks in any sense of the word, and to lay it on the line fairly and squarely, that teaching these people how to make jet engines, machine tools, textile machinery and how to generate electrical power cheaply, as well as how to drill for oil and then refine it after it has been obtained, is just as effective a build-up in war potential as is the supplying of actual munitions of war and the related materials, such as rubber and food.

The excuse, so often heard by those who transact the current trade, to the effect that our more rapidly advancing technology will automatically put us in the most advantageous position in the event of a trial at arms, is no longer valid, and there is serious doubt as to the validity of this argument for at least, the last twenty years.

True, the U.S. is a rich and resourceful country, but there is a limit to everything, and while the starry-eyed people predict decisive aerial fights using pilotless guided missiles, the fact remains that the MIG-15, at a basic $50,000 cost, is now opposed to our fighters costing five to six times this figure, and the author has yet to encounter an aircraft authority willing to concede that the U.S. version is five to six times as good as its opponent, or for that matter, twice as good.

The conclusion is inescapable. Good, though our technology undoubtedly is, it needs stepping up in tempo of achievement, if we are to maintain that technological edge that our inferiority in numbers of manpower, automatically and insistently demands.

VANADIUM ASH PROBLEMS IN OIL FIRED BOILERS

BY FRANK E. CLARKE

THE AUTHOR

graduated from Western Maryland College in 1935 with A.B. degrees in chemistry and education. Studied advanced physical chemistry for one year at University of Maryland and taught chemistry for four years before entering the Boiler Water Section at the E.E.S. Chemical Laboratory in March 1941. He became Head of the Boiler Water Section in 1942, Head of the Chemical and Physical Branch in 1946 and Head of the Process Branch of the Chemical Engineering Laboratory in March 1951. Since 1942 he has been responsible for Naval boiler water treatment and diagnosis of failed boiler tubes submitted by the Fleet. He is one of the Navy's principal consultants on water treatment and boiler problems.

Vanadium bearing, residual fuels have been a continuous source of fireside problems in boilers at the Naval Engineering Experiment Station during the past decade. They have produced a variety of troublesome deposits in saturated tube nests, played havoc with refractory and caused serious wasting of superheater tubes. While these furnace problems resemble those of Fleet boilers, sea water contamination played no part in them. Their occurrence illustrates the potential destructiveness of fuel ashes and the need for fundamental studies of ash constituents.

DAWN OF SLAGGING

The Station's first fuel ash problems consisted of serious superheater slagging in automatic, forced circulation, high temperature, steam generators of the type illustrated in Figure 1. These oil fired boilers produced approximately 50,000 pounds per hour or steam of 1200 psig. and 1000°F superheat. The first unit, a Babcock and Wilcox Model 2M was installed in 1937 and operated intermittently without trouble until 1942, when slagging of the superheater began. Deposition was most pronounced in the primary superheater circuit immediately after the generating nest. Lava-like deposits developed so rapidly in this area that the tubes were completely embedded and the gas passages virtually closed after several hundred hours of operation. Water washing was relatively ineffective in removing the deposits and it was necessary periodically to cut out the superheater and deslag it mechanically. Eventually, gas channeling from slag blockage, and unavoidable mechanical damage during cleaning ruined the

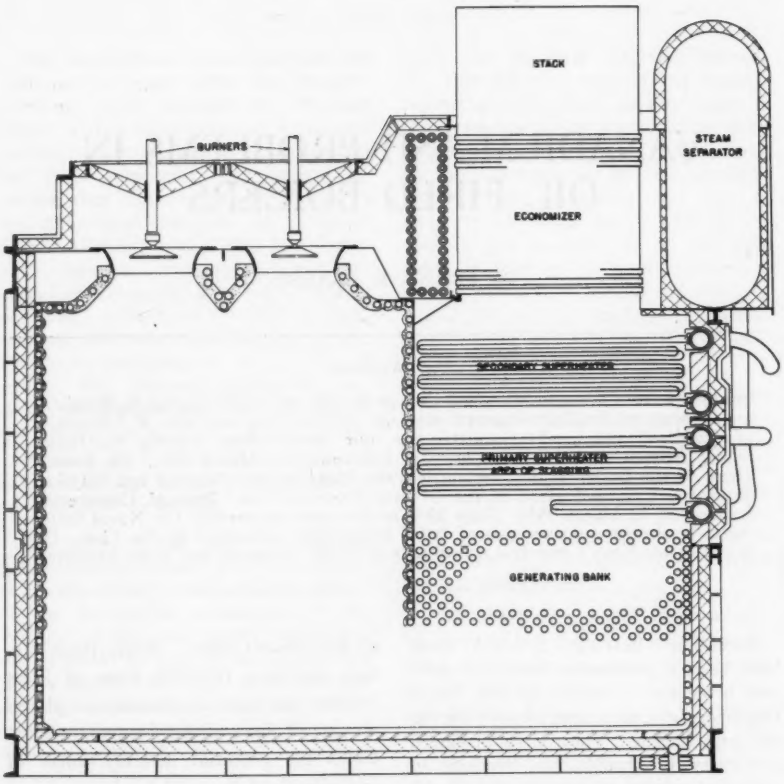

FIGURE 1—Babcock and Wilcox Model SM-9L Boiler.

superheater. The boiler was surveyed in favor of the Babcock and Wilcox Model SM-9L shown in Figure 1. This boiler was installed in 1945 and operated for approximately a year before two large boilers were installed to meet an increased demand for high pressure steam. It was plagued with the same type of superheater deposits.

During the period of serious slagging in the high pressure generators, a Babcock and Wilcox, sectional header 300 psi boiler and a Yarrow A type 400 psi boiler operated in the same fire-room, on the same fuel without furnace troubles. The sudden occurrence of slags in the high pressure units and the immunity of the low pressure units suggested that both fuel ash quality and boiler design influence ash deposition. Experience with two high pressure, power plant boilers installed in 1945 has provided more information on the importance of these factors. Most of the observations and data in the remainder of this paper are based on the power plant boilers.

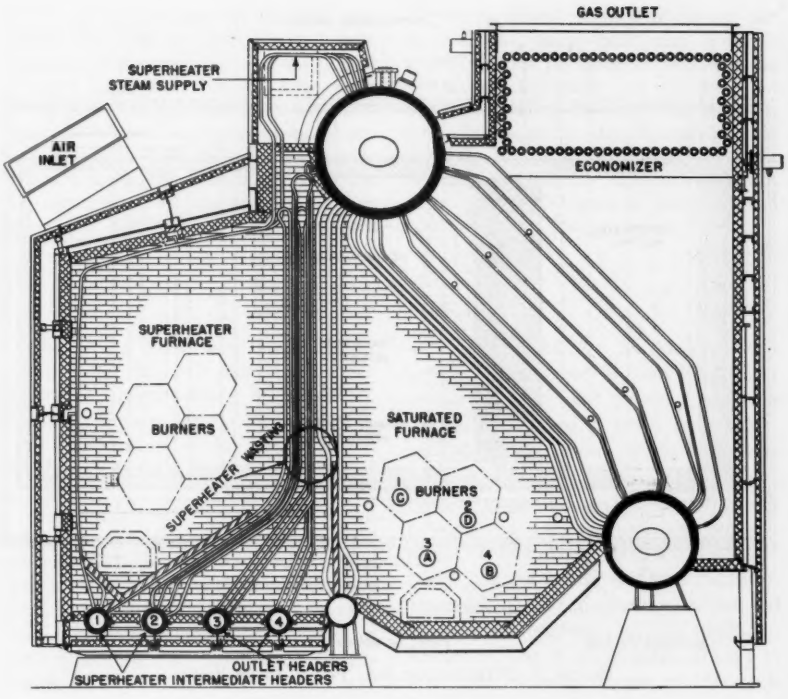

FIGURE 2—General Arrangement, Power Plant Boiler.

TABLE 1.—DATA ON POWER PLANT BOILERS

Type	*Foster Wheeler Express*
Boiler furnace volume, cu. ft.	687
Superheater furnace volume, cu. ft.	751
Generating surface, sq. ft.	7,125
Superheating surface, sq. ft.	1,895
Generating tubes, number, size	1,677 (1″ x 0.134″)
	120 (2″ x 0.24″)
Superheater tubes, number, size	351 (1″ x 0.134″)
Design pressure, psi	1,650
Design steam temperature, °F	1,000°F
Design capacity, lb/hr	180,000
Stack temperature, °F	580 to 615

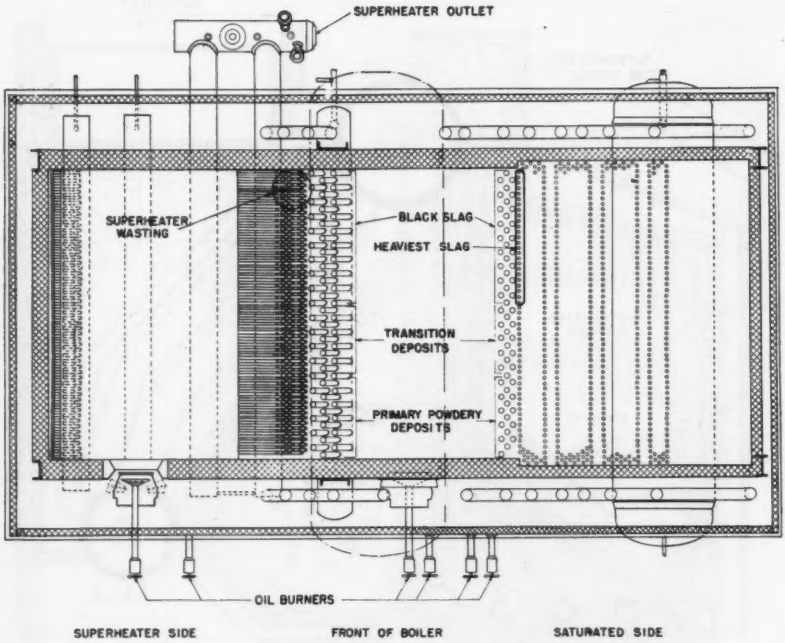

FIGURE 3—Plan Section AA, Power Plant Boiler.

CHARACTERISTICS OF POWER PLANT BOILERS

The pair of boilers in question were produced by the Foster Wheeler Corporation on a special Navy contract. An identical pair were installed at the Navy Boiler and Turbine Laboratory for experimental use. They are divided furnace, single uptake units of the type illustrated in Figure 2 and 3 and are designed to supply 180,000 pounds per hour of superheated steam at 1500 psi and 1000° F. Pertinent dimensions and design data are given in Table 1.

These boilers are operated with semi-automatic combustion and feedwater controls, using Todd duplex fuel oil burners with standard nozzles. Sprayer plate sizes range from 45-T-15 to 14-T-09 depending on the steam load. The former is a four slot plate which handles about 500 pounds per hour of heavy fuel. The latter has six slots and burns about 2000 pounds per hour.

At present, the burners are lighted and secured in the order of the numbers shown in Figure 2, except that low loads are carried on Burners 1 and 3. Burner 4 is used only at very high loads. All sprayer plates are changed when variation in steam demand boosts the fuel oil pressure above 300 psi or drops it below 200 psi.

Since their installation in 1945, the boilers have been used exclusively for production of saturated steam, except that the superheaters were subjected to one trial run of approximately 2 hours.

It is normal practice to operate one boiler for 1000 to 1500 hours before securing it for cleaning and switching the load to the other boiler. Thus, each of the pair operates approximately 4000 hours per year. Unforeseen problems such as pump failures sometime result in short operating periods. During the five day work week the operating boiler steams at 800 psi and produces from 50,000 to 80,000 pounds of steam per hour. The steam load may drop to 25,000 pounds per hour or less over the week-end, depending on the tests in progress. All of the saturated steam is passed through the idle superheater nest in order to protect it against overheat. It emerges from the superheater at approximately 750 pounds pressure and 650 °F.

QUALITY OF BOILER FUEL

The Power Plant uses Grade Heavy Navy boiler fuel oil purchased under Military specification MIL-F-859A. Table 2 compares the chemical and physical requirements of this fuel with that of Navy Special used in the boilers of this Fleet.

The two fuels are similar except for the lower viscosity in the special grade which is obtained with cutter stocks. Both are residual fuels which can vary considerably in quantity and quality of ash, depending on the source of the crude.

Nearly all of the Station's present supply of heavy fuel is from East Coast refineries. It is sent to the Station in barges and stored in metal tanks adjacent to the fire-room. From here it is pumped through strainers and fuel oil heaters to the boilers. Every shipment is analyzed for specification requirements before it is pumped into the tanks. Except for the fact that the Furol viscosity at 122° F averages about 160 these fuels conform to the limits in Table 2. The water content always is low. For example, during an 18 month

TABLE 2.—CHEMICAL AND PHYSICAL PROPERTIES OF NAVY FUEL

Determination	*Limit*	
	Heavy	*Special*
Flash point, closed cup (min.) °F	150	150
Fire point (min.) °F	200	200
Viscosity, at 122°F. (max.) SSF	150	.....
Viscosity, at 122°F. SSU	.....	110–225
Ash (max.) percent	0.12	0.10
Water, by distillation (max.) percent	0.5	0.5
A. P. I. gravity (min.)	10.0	11.5
Pour point, upper (max.) °F	50	15
Carbon residue (max.) percent	.....	15
Sediment by extraction (max.) percent	0.15	0.12
Water and sediment (max.) percent	.....	0.5
Thermal stability (NBTL heater)	Pass	Pass
Explosiveness (max.) percent	50	50

TABLE 3.—TYPICAL DATA ON ARUBAN FUEL SAMPLES

Determination	*Tanker 1*	*Tanker 2*	*Storage Tank*	*Supply Barge*
Gravity	14.0	13.6	14.5	14.0
Flash point, °F	188	192	200	200
Furol viscosity, 122°F	175	187	167	171
Pour point, °F	20	25	20	.....
Bottom sediment and water %	0.1	0.1	0.7	0.3
Sediments by hot filtration, %	0.4	0.4	.....	.....
Explosivity, %	32	30	40	.....
Sediment by extraction, %	0.05	0.03	.....	.....

period it averaged 0.15% and ranged from virtually 0 to 0.3%, with the exception of a single sample that contained 0.7%. The sediment content conforms to the specification requirement.

These East Coast heavy fuels are predominantly products of foreign crudes, particularly South American. They are relatively high in vanadium ash content and in proportion of vanadium to other ash constituents. Tracing a recent shipment showed it to be an Aruban fuel produced from Lake crude and containing about 95% residual stock with small percentages of Diesel fuel and visbreaker stocks from the crude. In this instance, the supply barge to the Station was filled from a storage tank in Baltimore, which in turn was filled from 2 separate tanker aliquots of the Aruban fuel. The data in Table 3 show the general nature of this fuel and the variation between the aliquots and the tank mixture.

Table 4 is a typical ash analysis furnished by the contractor for this type of fuel.

TABLE 4.—TYPICAL ASH ANALYSIS FOR ARUBAN FUEL*

Constituent	*Per Cent*
Aluminum Oxide, Al_2O_3	0.59
Calcium Oxide, CaO	2.46
Iron Oxide, Fe_2O_3	2.24
Nickel Oxide, NiO	1.05
Sodium Oxide, Na_2O	10.38
Silica, SiO_2	0.63
Sulfate, SO_3	29.13
Vanadium Oxide, V_2O_5	44.29

* Total ash content 0.07%.

The vanadium oxide content may range to 71% of the ash. Analyses at the Station have shown values from 37% to 66%, with approximately 8% of sodium oxide.

PATTERN OF FIRESIDE DEPOSITS

The heavy residual fuels produce interesting patterns of furnace deposits in the power plant boilers. When examined after normal steaming periods of 1000 to 1500 hours, they generally show a definite transition in physical properties and appearance from the front (burner end) to the rear of the furnace, and somewhat less pronounced transitions from the floor to the roof and from the fire-row tubes to the remote tubes. The forward, fire-row, generating tubes, presumably the coolest tubes in the boiler, tend to develop granular, nonadherent, deposits in a variety of colors from greenish white to brilliant dark

FIGURE 4—Granular Deposits on Forward Tubes.

green. The granularity gradually diminishes in favor of powdery deposits on passing inward through the superheater screen tubes. The granular area sometimes contains hollow, icicle-like projections on the following sides of the tubes. Examples have been found approximately ½ inch in diameter and about two inches long. Figure 4 shows the front tubes in a saturated nest after a typical steaming period. The white areas are the light colored, granular deposits, and the dark areas are similar

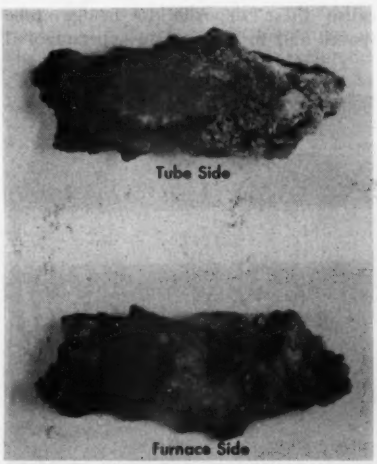

FIGURE 5—Transition Slag from Central Tubes.

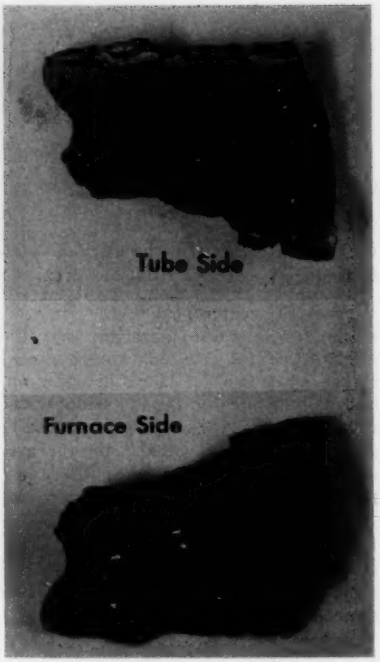

FIGURE 6—Advanced Transition Slag, Central Tubes.

deposits with superficial black coatings. The light colored debris on the furnace floor consist of deposits dislodged during the inspection.

In the central portion of the fire-row the deposits form as compact slags. The mildest forms (forward) have a salt cake or cake icing-like consistency and often are greenish-yellow or greenish-brown on both the fireside and tube-side. Figure 5 shows the relatively light color of a typical deposit from this area. The more advanced stages of the transition slag have finer grain structures and less vivid colors. They are apt to be pale, greenish-brown on the tube-side and dark brown or brownish-black on the fireside. Cold samples show a pattern of radial crystals. Figure 6 shows

FIGURE 7—Black Slag from Rear Tube.

the contrast between the fireside and tube-side of a deposit from this area.

From the center part of the fire-row to the rear of the furnace, the deposits always are fully fused, homogeneous slags. They are jet black in color on both the fireside and the tube-side; however, the tube-side usually has a soft, satin black texture whereas the furnace side is glassy in appearance. Between these two extremes there is a remarkably distinct structure of radial crystals. Figure 7 shows the fireside of a ¼-inch layer of this slag from a one-inch generating tube. The microstructure of the same sample is shown in Figure 8.

The compact black slag is heavier on the leading sides of the tubes, though it may extend all the way around them. Deposits on the 2-inch fire-row tubes range from 1/16-inch to ⅛-inch thick after 1000 hours of steaming. The thickness is greater on the first several rows of 1-inch generating tubes behind the 2-inch screen tubes. Black slags more than ¼-inch thick have been found in this area. Prolonged steaming periods cause these deposits to bridge tube spaces and to accumulate superimposed

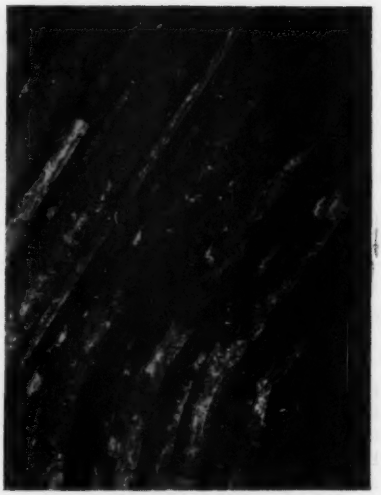

FIGURE 10—Slag Bridging, Rear Roof Tubes.

FIGURE 8—Microstructure of ¼" Black Slag.

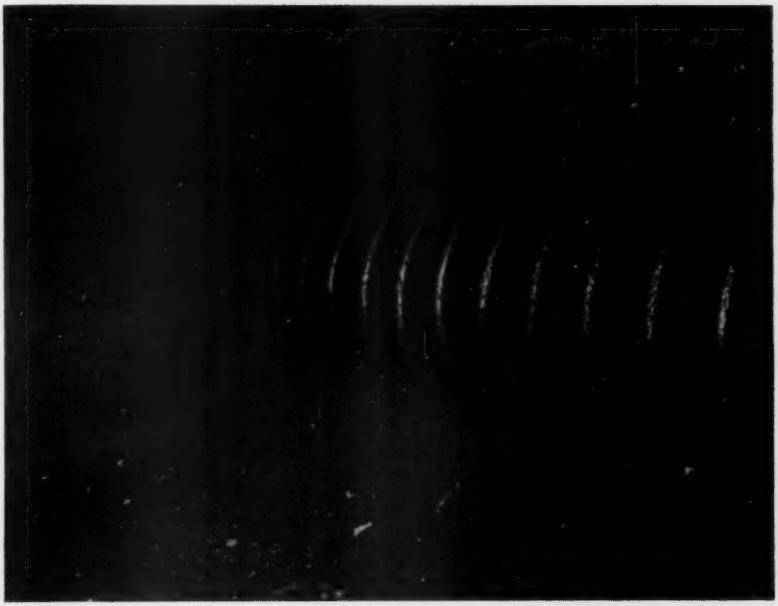

FIGURE 9—Black Slag on Rear Superheater Screen.

deposits of different types. Figure 9 shows the rear tubes of a superheater screen with shiny, compact coatings of black slag. The scattered white splotches represent islands of secondary deposits. Figure 10 shows roof tube bridging by heavy slag deposits developed in 1000 hours operation during which 12,500 barrels of heavy fuel were burned.

The deposit pattern discussed in the preceding text is not the only one which has been observed, though it is a common one. Occasionally, the forward tubes are coated with powdery organic deposits after short periods of operation. These carbon residues presumably result from oil impingement. In certain instances thin, fully fused, black slag coatings have been found on the forward tubes as well as on the after tubes. Powdery white deposits on forward tubes and scattered, heavy, salt-like deposits also have been observed. The latter occur primarily as secondary coatings on black precoat slags in the rear of the furnace.

COMPOSITION AND PROPERTIES OF DEPOSITS

Analyses show that while the major constituents in all of the furnace deposits are the same as the major constituents of the heavy fuel ash, their proportions vary markedly from one furnace area to another and rarely agree with the typical proportions of the ash. Some of the granular deposits at the burner end of the fire-row have much higher proportions of sulfate ions than are found

TABLE 5.—VARIATION IN FIRESIDE DEPOSITS

Type of Deposit	*General Location*	*Color*	*Water Solubility, %*	*Melting Point, °F*	*Major Constituents, %*		
					Vanadium	*Sulfate*	*Sodium*
Amorphous Hydrated Dehydrated	Forward Tubes	Greenish Black	89.2	100 900	9.4	55.6	9.4
Black Crystalline Slag	Primary Coating, After Tubes	Jet Black	32.9	1000	35.1	23.4	9.5
Overlay Salt-Like Slag	Secondary Coating, After Tubes	Greenish White or Yellowish White	88.0	Sublimed 1900-2000	3.9	64.5	20.2

in the ash. They are hygroscopic, readily soluble in water and yield extremely acid water extracts. These deposits also may have abnormal proportions of sodium when compared with the ash. Powdery deposits from the front of the furnace and the idle superheater have less sulfate and more sodium than the deposits just described. They are water soluble but are considerably less hygroscopic and less acidic.

The transition deposits from the central tubes are less acidic and frequently contain relatively high ratios of sodium and sulfate to vanadium. The reverse is true of the compact black deposits on the rear fire-row tubes, which are very high in vanadium. The proportions are reversed again in the salt-like secondary slags which grow on the primary black slags. These are predominately sodium sulfate.

The intermediate products show less water solubility than the forward products, and the black deposits are extremely insoluble. Water solubilities, as low as 16% have been obtained on these slags.

Vanadium compounds are major constituents of all of the deposits and principal constituents in many of them. Table 5 indicates the variation in major constituents and pertinent physical properties, which may occur during a single steaming period.

Minor constituents like the compounds of calcium, magnesium, nickel, chromium, lead, and iron are present in most of the deposits. Strangely enough, the soft, tube side layer of the black slag may contain insoluble lead compounds up to 6%. The fact that vanadium and lead behave similarly may account for this.

The amorphous nature of the forward deposits, and the lack of published x-ray diffraction patterns on many vanadium compounds makes it difficult to determine the molecular forms of the elements which make up the several classes of deposits. The high concentrations of sulfate and acidity in the granular deposits suggest vanadyl hydrotrisulfonates like $2(VO)SO_4 \cdot H_2SO_4 \cdot \times H_2O$. The properties of these compounds as described in Mellor's "Treatise on Inor-

ganic and Theoretical Chemistry" are almost identical to those observed. Similar materials have been prepared by the syntheses described therein. In addition, the black slag has been converted to the amorphous, granular variety by treatment with sulfuric acid and then reformed by heating.

Table 6 gives probable constituents of three slags based on such properties as water solubility, melting point, color and acidity.

TABLE 6.—COMPOSITION OF TYPICAL SLAGS

Probable Constituent	*PER CENT*			
	Amorphous (Forward)	*Primary Black (Fireside)*	*Primary Black (Tube-Side)*	*White Overlay*
Na_2SO_4	.....	23.99	10.07	46.78
$NaHSO_4$	49.22	8.92	.....	26.36
$CaSO_4$	.....	.....	.....	6.73
$MgSO_4$	3.32	.....	.....	4.85
$NiSO_4$	.....	.....	.....	3.14
$FeSO_4$	3.89	.....	.....	.....
$2(VO)SO_4 \cdot H_2SO_4$*	14.73	.....	.....	.....
$(VO)_2(SO_4)_3$	.....	.....	1.20	.....
$Pb(VO_3)_2$	.....	.....	11.76	.....
V_2O_5	.....	.....	4.44	.....
V_2O_4**	9.58	57.21	55.04	5.16
NiO**	1.03	1.03	0.18	2.62
CaO	.....	.....	.....	0.12
MgO	.....	.....	.....	1.23
Fe_2O_3	.....	0.36	1.83	2.95
SiO_2	2.91	0.55	0.86	1.41
H_2O	14.75	0.97	0.96	0.59

* This compound generally hydrated with one to five molecules of water.

** V_2O_4 and NiO could exist as a NiV compound in a reducing atmosphere.

MECHANISMS OF SLAGGING

The variation in proportion of major constituents in different parts of the furnace suggests selective deposition related to furnace temperature gradients, combustion characteristics, or ash properties. Neither fuel impingement nor uniform ash deposition would explain these variations, since both should yield approximately the same ratio of vanadium to sodium from front to rear. It is improbable that a mechanism exists for concentrating sodium in some areas and vanadium in others once a uniform ash has been deposited.

The selective deposition of vanadium compounds on the hot, rear tubes may mean that the vanadium is derived from organic complexes which burn while passing through the furnace and finally deposit as ash or molten droplets on the last tubes. On the other hand it could mean that low melting vanadium com-

pounds, traveling as molten droplets in the gas stream, select the hottest tube surfaces because they wet more readily. Such wetting is most apt to occur when the tube skin temperature approaches the melting points of the compounds involved. This is the "icing" mechanism proposed by the author in an earlier issue of the JOURNAL. While the rear row tubes of 800 psi generating nests probably are several hundred degrees below the melting points of ordinary vanadium compounds like V_2O_5, they could easily approach melting points of unusual vanadium compounds like the hydrotrisulfonates. The black slag which recurs in this area melts at about 1000° F.

These hypotheses by no means exhaust the possible mechanisms. It is conceivable that selective deposition is based on ash classification due to relationships between particle size and gas velocities. The high concentrations of sulfate and acidity in the granular deposits show that sulfur oxides influence deposition. The general character of the deposits in the central, transition zone would appear to indicate that deposits can be altered considerably in composition and appearance after they have been laid down. The greater thickness of the black slags several tubes behind the fire-row may mean that this is another selectivity point based on skin temperature, gas pattern or particle size, or simply that the fire-row deposits are thinner because of continuous dripping under the intense heat.

Even though powdery deposits have been found on forward tubes, there is no proof that they are a necessary primary stage of the other deposits. Steaming periods as short as eight hours have developed scattered meandering islands of fused slag on the forward tubes and uniform, thin, dark blue slags on the after tubes. Figure 11 shows the scattered deposits. Both the islands and the uniform coating contained about 25% vanadium.

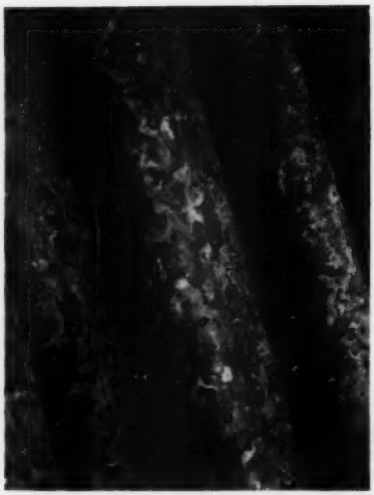

FIGURE 11—Slag Islands After 8 Hours Firing.

Either fusion of powders or coalescence of molten droplets could have produced the islands. Whatever their source, this early occurrence of fused deposits on clean tubes shows that true slagging can start immediately on lighting off and that it need not involve an "induction" period.

The phenomenon of precoat and secondary slagging continues to be a prominent and puzzling one. Long period operation generally yields deposits with ⅛" or more of vanadium tube-side slags, overlaid with heavier deposits of sodium sulfate type slags. The reverse structure never has been found in these boilers. Variation in fuel composition does not explain this stratification because both the heavy fuel and the tube-side layers are consistently high in ratio of vanadium to sodium. The structure suggests that vanadium compounds deposit first because of lower melting points, better wetting properties, or other characteristics and then instigate deposition of other slags by mechanical trap-

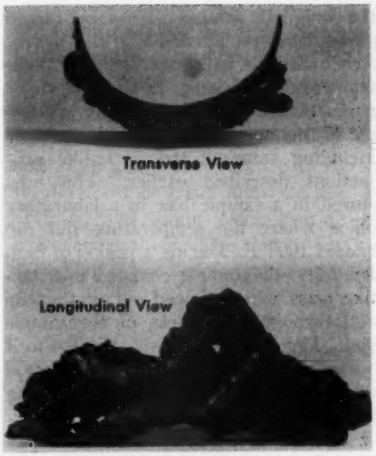

FIGURE 12—Primary Slag with Trace of Secondary Slag.

ping or thermal insulation effects. This does not explain why the proportion of sodium is higher in the secondary slags than in the fuel. It may be that vanadium compounds tend to separate from mixed deposits and collect on the tube surfaces after deposition has occurred.

Figure 12 shows a primary vanadium slag with rivulets of secondary slag just starting to form on its surface. This would appear to support the theory that

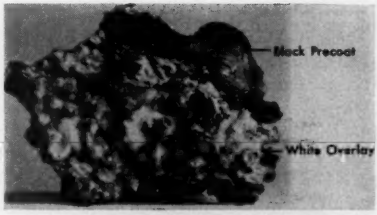

FIGURE 13—Precoat Slag With Massive Overlay.

the precoat slag is an instigator of further slagging. A similar vanadium precoat slag with a massive secondary deposit of sodium sulfate type slag collected during long period operation is shown in Figure 13. This deposit was taken from a 1-inch tube behind the 2-inch tube screen where it had completely bridged a tube space. The oblique black area in the upper right hand corner is the vanadium primary slag.

Laboratory tests on hygroscopic granular deposits from the front of the boiler have revealed potential slagging mechanisms more interesting, and perhaps more dangerous, than the one already suggested. Figure 14 shows a sample of such deposit before and after heating in a laboratory oven at 125° F. The original material on the left was water soluble, gummy, amorphous, and ex-

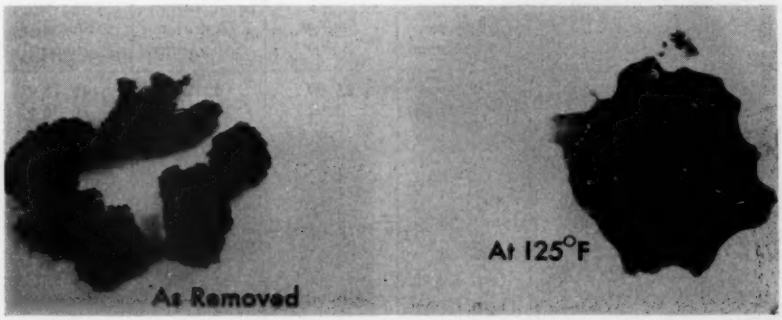

FIGURE 14—Low Melting Amorphous Deposit.

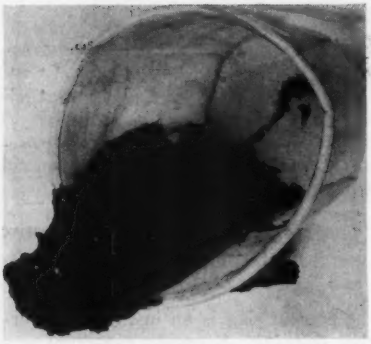

FIGURE 15—Amorphous Deposit Fused at Room Temperature.

tremely acidic. Its probable composition is shown in Column 1 of Table 7. The low temperature of 125° F. converted it to a brownish-black puddle which solidified into a typical, glassy slag. On re-exposure to the air, this brittle slag button gradually disintegrated into a green sticky material similar to that from which it came. Adsorption of atmospheric moisture was responsible for this change and obviously contributed to the unusual thermal characteristics of the original sample. In very humid atmospheres pseudo fusion of this hygroscopic deposit will occur at still lower temperatures. Figure 15 shows a paper cup which originally contained a sample of the amorphous material, probably including some of the icicle-like projections described earlier. This was stored in a sample box in a laboratory office where the temperature did not exceed 100° F. During a period of high humidity, the sample changed to a tar-like mass which flowed out of the cup and through the cracks of the sample box. The angular deposit attached to it outside the cup is not a part of the fluid mass, but a piece of black vanadium slag to which it fused.

FIGURE 16—Amorphous Deposit After Desiccation.

TABLE 7.—COMPOSITION OF BI-LAYERED SLAGS

Probable Constituent	*Primary Black*		*White Overlay*	
	Destroyer Superheater	*Station Boiler*	*Destroyer Superheater*	*Station Boiler*
Na_2SO_4	35.95	23.99	42.29	46.78
$NaHSO_4$	.....	8.92	.....	26.36
$CaSO_4$	0.71	.....	6.56	6.73
$MgSO_4$	1.87	.....	10.72	4.85
NiO	Trace	1.03	5.19	2.62
V_2O_4	49.34	57.21	18.79	5.16
Fe_2O_3	2.26	0.36	3.20	2.95
SiO_2	0.67	0.55	0.74	1.41
H_2O	3.44	0.97	8.55	0.59
CaO	.....	.....	.....	0.12
MgO	.....	.....	.....	1.23
$NiSO_4$	.....	.....	.....	3.14

The roll of moisture in this transition was confirmed by desicating a sample of the original amorphous material over calcium chloride and then melting it. With water gone, the material no longer melted at low temperature, but it did melt at about 900° F. Figure 16 shows the desicated material after heating to 125° F. and again after heating at high temperature. The latter was a typical slag and was not affected by exposure to atmospheric moisture after cooling.

This low temperature mechanism may explain why slagging sometimes occurs suddenly in boilers which are operated intermittently. Hygroscopic deposits could adsorb moisture during the interim, fuse to the pseudo slag on losing moisture and thereafter develop into true slags. This mechanism would not be expected in boilers which operate continuously between cleaning periods.

EFFECT OF DEPOSIT ON FURNACE REFRACTORY

The effects of heavy fuel deposits on furnace refractory are as troublesome as their effects in the gas passages. The slags are potentially destructive to all types of furnace refractory. Sodium sulfate attacks alumina and silica-type bricks at high temperatures, even though it has very little effect on basic and neutral varieties. The vanadium compounds will destroy virtually every type of refractory, as well as every type of metal. Combustion efficiency and flame distribution markedly affect the magnitude of refractory attack, by increasing the quantities of deposit and reaction temperatures in certain furnace areas.

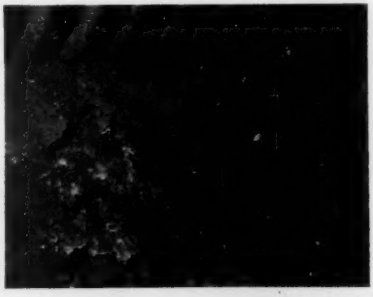

FIGURE 17—Floor Damage Beneath Generating Nest.

Refractory damage was particularly severe during early operation of the power plant boilers, when ash effects were accentuated by combustion problems. Large quantities of slag flowed down the fire-row tubes to the inclined floor directly beneath them and com-

FIGURE 18—Distintegrated Floor Brick.

FIGURE 19—Vitrified Floor Brick.

pletely disintegrated the brick work. Figure 17 shows this damage below a main generating bank. Figure 18 is a close-up view of a brick from this area.

FIGURE 20—Interior of Vitrified Floor Brick.

The fire brick in the horizontal furnace floor, where the molten slags collected, tended to vitrify rather than disintegrate. Figure 19 shows a brick from this floor with its upper portion turned into a hard, black, glass-like material. Figure 20 is the underside of a ½" slab of similar "glass" removed from the furnace floor.

After a number of devastating preliminary firing periods, this effect on refractory was markedly reduced by changing the order of the burners from A, B, C, D to 1, 2, 3, 4 (Figure 2). Some damage of the same type continues to occur in proportion to the rate of firing and the period of operation.

EFFECTS OF ASH ON TUBE EXTERIORS

Serious cases of external tube wasing occurred in the idle superheaters. The damaged tubes were the rear nine in the outlet pass immediately behind the superheater screen tubes at approximately top burner height (four feet above baffle) and near the rear wall of the furnace. The damage was discovered in 1951, six years after installation of the boilers. It consisted of the peculiar smooth, deep, general cratering illustrated in Figure 21. Wall thinning was greatest on the leading sides of the tubes and the perforations occurred on that side. The extent of wasting is shown in Figure 22. This damage was not caused by fireside deposits, since the damaged tubes were relatively clean. It was not the type of cratering that results from excessive moisture, leakage or soot and there was no evidence of these conditions in the area. Tests on the sister boilers at the Navy Boiler and Turbine Laboratory after discovery of this damage showed that Tube 26 (rear) in the idle superheater attained a temperature of 1200° F. at 50,000 pounds per hour load, despite the flow of saturated steam through it and approximately normal superheater outlet

FIGURE 21—Wasted Superheater Tube.

temperatures. The highest tube temperatures were obtained with Burners B and D (Figure 2), in operation but Burners A and D were almost as bad.

FIGURE 22—Cross Section of Wasted Tube.

Burners A and B yielded temperatures approximately 350° F. lower at the same steam loads. Increasing the steam load beyond 50,000 pounds per hour did not increase tube temperature and operating pressure had no significant effects.

The appearance of these superheater tubes and the tube temperature data indicate that the damage was a high temperature effect of vanadium vapors. These effects have been discussed by a number of investigators, and generally are thought to occur at temperatures of 1000° F. or above when vanadium type ashes and chrome-nickel tubes are involved. All of the tubes may not have attained this temperature, but the vanadium deposits on and between the screen tubes immediately in front of them undoubtedly exceeded it. When the fire-row tubes are viewed through the observation ports, bright, red hot deposits can be seen above the brilliant yellow color of the furnace atmosphere. In some instances, the tubes are glowing from top to bottom. It is possible that vanadium compounds vaporized at high skin temperatures might react with nearby tubes whose temperatures are appreciably lower.

External wasting of the saturated tubes has been decidedly less pronounced. Some evidence of it has been seen on the inner nest tubes near the rear of the furnace, where vanadium deposits are heaviest and temperatures are highest; however, no failures have occurred. Protection of the tubes by slag deposits and the lower metal temperatures probably account for this.

RELATION TO FUEL ASH PROBLEMS OF THE FLEET

While the fuel ash problem described in this paper occurred primarily in saturated nests and resulted entirely from the ashes of heavy fuel, they resembled the furnace problems of the Fleet in many pertinent respects. In both cases, powdery or granular deposits appear to be the mildest form of deposition and high temperature and prolonged operation tend to intensify slagging. The phenomenon of vanadium precoat slagging and superimposed, massive, sodium sulfate slagging occurs in Fleet superheaters fired with Navy special fuel just as it does in the Station's boilers. Figures 23 and 24 show the remarkable similarity between bi-layered slags from a power plant boiler and a destroyer superheater. Table 7 shows that the corresponding layers are almost identical in composition. Similar bi-layered superheater slags have been noted in other Naval vessels.

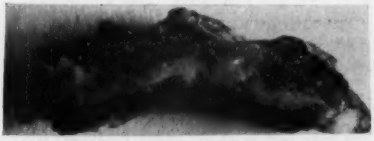

FIGURE 23—Bi-layered Slag, Station Boiler.

FIGURE 24—Bi-layered Slag, Destroyer Superheater.

Continuous operation of the Station boilers has made it impossible to study Fleet reports that slag stoppage occurs suddenly after periods of normal operation. However, as indicated earlier, the physical properties of certain transition deposits easily could lead to "freeze up,"

during intermittent operation. The absence of sea water from the Station's heavy fuel has prevented a study of the effect of this added contaminant.

The differences between the Station's furnace problems and those of the Fleet probably are more important than the similarities. They serve as a prevue to possible effects of switching to heavier, less combustible fuels and show the potentialities of fuel ash constituents in the absence of other contaminants. They cast serious doubts on the propositions that fuel ash problems can be overcome by such limited corrective measures as water washing and fuel desalting.

CONCLUSIONS

This case history has demonstrated that fuel ash constituents can promote a variety of serious fireside problems in the absence of sea water contamination. It has provided an interesting study of vanadium deposits and posed many puzzling problems regarding their furnace reactions. These puzzles point to the need for laboratory studies of fuel ash constituents. Attempts to explain and correct fireside deposits probably never will be completely successful until better data have been obtained on the mechanics of slagging.

HIGH-PRESSURE INSTRUMENTATION

ACKNOWLEDGMENT

This article discusses some recent advances and probable extensions in the art of high-pressure instrumentation. Written by Mr. P. W. BRIDGMAN, of The Research Laboratory of Physics of Harvard University, it was published in the January 1953 issue of "Mechanical Engineering."

LEGENDS CONCERNING HIGH PRESSURES

Doubtless there are numerous reasons why the high-pressure field has not been cultivated more extensively. Some of the reasons are good and some not so good. In past years there were almost fantastic legends about the discouraging and strange properties of matter under the action of high pressure, some of these legends mutually contradictory. Thus there was the legend that water was absolutely incompressible and could be forced through the pores of solid metal by sufficiently high pressure. This legend goes back to the days of the Florentine Academy and the first attempts to detect the compressibility of water, and persisted to at least the time of Amagat, who thought that he had forced mercury through the pores of a solid steel casting with a pressure of 3000 atm. The cynical modern explanation is that Amagat's casting had flaws in it, and that the tinsmith of the Florentine Academy did not justify his probable reputation for perfect craftsmanship.

This legend of the penetration of solid matter by a high-pressure liquid has another form in the stories of tightly stoppered bottles lowered into the sea and pulled up again full of water. The conclusion was drawn that the water must have been pushed through the solid glass walls, because the stopper showed no evidence of damage. Anyone who has witnessed the dramatic shrinkage of a cork under a hydrostatic pressure of only a few atmospheres knows the answer to that one. On the other side, legend has it that the pressures in the depths of the ocean are so utterly inconceivable that only a few miles down the sea water has been compressed by the stupendous pressure to the density of steel, so that all the steel vessels that have ever sunk are forever floating at this depth, buoyed up by the dense liquid.

ACTUAL DIFFICULTIES

Legend aside, there are certain difficulties peculiar to the high-pressure field and the fact that these were not at once surmounted played its part in the slow development of the field.

In the first place there is the fact that at pressures at all high the subject of experiment has to be enclosed in a heavy pressure vessel which precludes direct observation and demands some indirect and perhaps unnatural method of measurement. Difficulties of this sort can usually be surmounted with sufficient ingenuity, particularly now that any desired number of electrically insulated

leads can be got into the pressure chamber. It is, however, still not unusual to encounter skepticism about the results of a pressure experiment because of the unperspicuousness of the apparatus, and I have often been asked how I can be sure that the high-pressure "ices," for example, are really solids.

Another difficulty is in the smallness of many of the effects under those pressures which can be reached with the simple apparatus of the conventional laboratory or shop. The scientific development of our subject may be said to have begun about 150 years ago with the proof by Canton that water was measurably compressible. Canton used in his proof the great magnification afforded by piezometers constructed on the pattern of overgrown thermometers. Although Canton proved the existence of a compressibility, his numerical value was in error by a factor of 4. One method of avoiding the error due to the smallness of many pressure effects was to make them larger by increasing the pressure. Here at once technical difficulties were encountered, in great part due to leak. So greatly were the difficulties arising from leak esteemed that it was hailed as a great and imaginative forward step in technique when Perkins generated pressures of 100 atm by lowering his apparatus with a rope into the sea.

The difficulty of correctly measuring compressibilities as small as that of ordinary liquids was further increased by the distortion which the containing vessels universally experience under the action of pressure. Two sorts of improvement were necessary before this difficulty could be surmounted. The theory of elasticity was not sufficiently understood, so that serious mistakes were made in calculating the corrections for distortion. For instance, as eminent a physicist as Jamin, of interferometer fame, did not understand that a hollow vessel of homogeneous material exposed to uniform hydrostatic pressure on its entire external and internal surface experiences a uniform shrinkage just as if it were part of a single solid piece. The other difficulty was that materials were not sufficiently uniform and homogeneous, but were full of flaws and strains, so that their deformation when exposed to hydrostatic pressure was far from uniform. It was not until the introduction of the Bessemer process of making steel plates that one could count on a piece of steel shrinking uniformly in every direction under a hydrostatic pressure, a property which enters essentially into our present methods of measuring the compressibility of solids.

NEW HORIZONS

By now these various difficulties have so far been met that I think we are in a position to accept the challenge of measuring any physical property of materials up to about 30,000 atm at room temperature. To exceed these limits other problems must be solved to which I would now like to invite the reader's attention. It is paradoxical that one of the greatest difficulties which at first opposed our entry into the high-pressure field, namely, leak of the transmitting liquid, disappears at pressures above 30,000. The simple reason is that there are no more liquids above that pressure (with only one or two inconsequential exceptions), all liquids having been frozen solid by the pressure. The problem of leak is replaced by a new problem, namely, to find some solid which remains sufficiently soft at such high pressures to transmit stress approximately hydrostatically. The solution of this problem does not appear hopeless, and I have already used silver chloride with considerable success in measuring the electrical resistance of metals up to 100,000 atm. The discovery of a suitable

transmitting medium is demanded all the more if one is to penetrate into the very inviting unexplored field of high pressure and really low temperature. Some work is already under way looking in this direction.

The supreme problem in pushing pressure to the limit is the strength of the containing vessel. The most natural method of solving this problem is to use stronger materials, something which of course will be done as soon as the materials are available. Already such an improvement in material has occurred at least twice in the history of our subject, first in the development of high-strength alloy steels with tensile strengths in the neighborhood of 350,000 psi, and second in the development of carboloy. Carboloy has a compressive strength nearly twice that of steel, and furthermore, under the action of pressure, loses its brittleness in tension and also becomes stronger in tension than steel. It is carboloy that has made possible my experiments to 100,000 atm or even higher. It appears at present that we cannot anticipate much improvement over the performance of carboloy as a material for high-pressure construction; even the diamond would probably be not more than 50 per cent better.

THE "CASCADING" PROCESS

It would seem to me that ultimately we must come to some sort of cascading process in the construction of our pressure vessels, that is, a nest of pressure vessels, with progressive increase of pressure from the outside in. Theoretically there is no limit to the pressures that can be reached in this way. The supreme example is afforded by nature itself, for the mammoth pressures in the sun and stars are built up by a cascading process. At the same time nature shows us the chief difficulty limiting practical use of the cascading process, namely, the difficulty of controlling and knowing what is happening in the inner members of the nest—it does need an astronomer to remind us that we know nothing directly of the interior of the stars, which are accessible to us only by calculation. In the laboratory I have applied one stage in the cascading process, but have not been able to proceed to the next step. Progress here evidently awaits a bright idea.

Pressures inside a cascaded apparatus may be either static or dynamic. Perhaps we shall eventually be able to control a static cascaded pressure, as in the stars, but I believe that for at least the immediate future we are going to get our new highest pressures dynamically, probably with explosives. Progress already is being made in this direction. It is evident that the method will be complicated and expensive, and that good numerical values are going to be hard to obtain. Probably, at least in the beginning, these numerical values will have to lean heavily on extrapolations from the region of controllable static pressure.

PHENOMENA AT HIGHER PRESSURES

What now are some of the phenomena which we can anticipate will make the new field of higher pressures interesting? First and foremost there are the phenomena of the electronic breakdown of the atoms which we are pretty confident occurs in the interior of the stars. Here the breakdown is in all probability complete, but at lower pressures, such as we can hope to reach in the laboratory, the breakdown will doubtless occur in stages. In fact, at least two cases are now known in which it is highly probable that a rearrangement of the elec-

tronic shells in the atom has been forced by pressure. When one considers the very great complication of the electronic structure of most atoms, one may anticipate a tremendous amount of detail in the process of complete atomic breakdown, so that the domain of pressures above 100,000 atm, say, may well exhibit a wealth of phenomena greater than shown by ordinary matter in the domain now accessible to us.

At pressures less extreme than required for atomic disintegration there are, I believe, a number of inviting prospects. It is now possible to combine pressures up to 50,000 atm and temperatures to 2000 or 3000 C. I cannot but believe that it will be possible to create many new substances under such conditions. In a range of less extreme temperatures the whole field of the properties of alloys under pressure is almost untouched. Thus I have very recently found that a pressure of 25,000 atm will produce an intermetallic compound of tin and bismuth. Under ordinary conditions the system bismuth-tin is a simple eutectic system with no intermetallic phases.

The possibility must always be kept in mind that new phases may be produced irreversibly if pressure can be raised high enough to push the substance over an intermediate hill of potential. An example of this is the conversion of ordinary yellow phosphorus into black phosphorus. We may anticipate instances of a similar effect on a less drastic scale. I have recently found examples. It is usually said that ordinary materials are perfectly elastic to hydrostatic pressure, and that any permanent change of density after exposure to hydrostatic pressure is evidence of internal flaws which are closed by the pressure. If, however, various sorts of glass are exposed to pressures above something in the neighborhood of 50,000 atm, permanent changes of density of several percent may be produced. On reflection this does not appear so strange, for the x-ray analysis of glass shows that the structure is not close-packed, but there are cavities on the atomic scale which offer the potentiality of rearrangement under pressures sufficiently high. It is now my opinion that, short of atomic breakdown, the only substances which are perfectly elastic under indefinitely high hydrostatic pressure are the perfect crystal lattices. It will be interesting to examine whether the plastics show permanent increases of density above some critical pressure, as do some of the glasses.

Another high-pressure field awaiting development is connected with the very great increases in plasticity of the metals produced by pressure, with enhancement of such physical properties as strength under the great cold-working permitted by the great plasticity imparted by pressure. For example, it is indicated that if a steel wire could be drawn through a die while completely immersed in a liquid under high hydrostatic pressure, increases of strength of the order of twice that ordinarily obtainable may be anticipated. The technique of wire-drawing under such pressures evidently offers difficulties, but there is no reason to think the difficulties are insurmountable.

SOME ASPECTS OF MEASURING HIGH PRESSURES

Finally, I should like to consider a few aspects of the problem of measuring pressure. The broad classification of pressure-measuring devices into primary and secondary is convenient and corresponds to laboratory practice. The primary pressure gage determines pressure by referring directly to the definition of pressure as force per unit area. The most usual forms of the primary gage are the mercury columns and the deadweight piston. In spite of the di-

rectness of measurement by these two primary gages neither is entirely free from correction; the mercury column must be corrected for temperature variations and the compressibility of the mercury, and the free-piston gage for distortion of piston or cylinder by the pressure under measurement. These corrections are under good control, so that primary measurement of pressure is capable of high precision.

It is perhaps worth mentioning that in principle there is at least one other method of finding the absolute pressure than by the use of a primary gage. This is by the use of the formulas of thermodynamics. Not all thermodynamic formulas in which pressure appears are capable of such use. For instance, the identical relation between the so-called "pressure coefficient," thermal expansion, and compressibility is one from which the dimension of pressure cancels from both sides of the equation, leaving nothing to set the standard of pressure. But there are other formulas in which there is a single term involving pressure connected by the equation with other terms into the measurement of which pressure does not enter. Any such equation in principle permits the determination of pressure, in that the unit of pressure must be so adjusted that the equation is satisfied. An example is the conventional expression for the Joule-Thomson coefficient, connecting the change of temperature with pressure at constant total heat to volume, specific heat, and thermal expansions. Other examples are the pressure coefficient of electromotive force of a cell, or the pressure coefficient of surface tension. I do not know whether the practical difficulties are so great as to preclude use of this theoretical possibility or not. It is at least obvious that use over any extensive pressure range would demand an integration for those substances whose coefficients vary appreciably with pressure.

An eventual problem is pressure measurement in the range above the freezing pressure of available liquids where pressure has to be transmitted by a solid. The simplest method will probably be most successful, namely, measurement of the total thrust on a piston of known area. Errors will be instroduced by friction, which now cannot be eliminated by rotation of the piston as is possible when pressure is transmitted by a liquid, and by distortion of the cross section. Friction can be minimized by making the diameter of the piston large compared with the thickness of the solid on which the piston acts and by the use of conical packing rings of minimum thickness to retain the solid. Distortion of the cross section can be determined from the displacement of probes let into fine holes in the wall of the pressure vessel. Pressures determined in this way will be used to locate various fixed points in the high-pressure domain, such as suitable transition points. There is at present one such fixed point, the transition point of bismuth in the neighborhood of 25,000 atm. By use of the measures just described it should be possible to determine this point to something of the order of 0.1 percent.

As a secondary measure of pressure any easily measured and reproducible property of matter may be used. The change of electrical resistance of a metal or an alloy is one such, and the manganin resistance gage has had considerable use. The chief difficulties with this gage are failure of complete reproducibility, especially wandering of the zero. These irregularities are due for the most part to internal strains, the effect of which to a large extent may be removed by suitable seasoning procedures. I have found in my work to 30,000 atm that the zero is stabilized much better after exposure to pressure of this magnitude than it is by the lower pressure of 12,000 atm, which was the pressure range of most of my earlier work. For

applications in which zero stability is of great importance and in which it is feasible to take unusual precautions to secure constancy of temperature, it probably will pay to use for the secondary resistance gage some soft metal which is incapable of storing as large internal strains as manganin. I have found two specimens of lead of different origin to have the same pressure coefficient of resistance within 0.01 percent.

Whatever the secondary gage it usually will have to be calibrated, and this calibration under most conditions will be made, not directly against a primary gage, but against some pressure fixed point which has been previously established once and for all against a primary standard. Such fixed points are offered by freezing and melting of various substances, or by polymorphic transition. Desiderata in such points are sharpness, that is, a unique pressure when approached from either direction, speed of attaining equilibrium, change of volume, or other change accompanying the transition large enough to measure easily, and absence of super- or subheating or pressing. There are not many transitions with all these properties. One convenient such point, which I have made fundamental in most of my work, is the freezing pressure of mercury at 0 C. This point also has been used by others.

FREEZING PRESSURE OF MERCURY

Hitherto I have located the freezing by the change of volume, which amounts to about 5 percent. This is large enough to be handled without too much difficulty, but one has to keep one's wits about one not to allow the piston displacement to stray outside the range in which both liquid and solid phase are present together. Appreciable quantities of mercury have to be used to give a change of volume large enough to control, and this means that the heat of melting is large enough to demand appreciable times for reaching temperature equilibrium. With my usual setup it was possible to determine a mercury fixed point with a difference of pressure of not more than 1 in 3000 as reached from above and below in a time of 2 hr.

Recently I have found that the determination of the mercury fixed point is much facilitated and accelerated by using as the indicator of the phase change the change of resistance instead of the change of volume. Resistance changes by a factor of fourfold on passing from liquid to solid, contrasted with the 5 percent change of volume. The mercury may be used in the form of a fine capillary, in which the total heat of freezing is so small that equilibrium is rapidly attained. By making the capillary out of lucite or other plastic one avoids the fracture of the capillary which would accompany freezing if glass were used. In determining the freezing point, one first, by suitable manipulation, freezes about half the mercury, and then by slight changes of pressure, which can be controlled by a 0.0001-in. Ames dial attached to the piston, causes the resistance to drift first in one direction and then in the other. In this way I have located the pressure of freezing within limits beyond the sensitivity of the manganin gage, that is, within limits less than the 1 part in 3000 just mentioned in 10 or 15 min.

A THEORY FOR CONSERVING OUR LOST B.T.U.'s

MILO C. CAUGHREAN

THE AUTHOR

was born 19 June 1889, in Nevada, Missouri. He was educated in the public schools in Ketchikan, Alaska. Early in youth he embarked on the study of Engineering and received his Chief Engineer's License at the age of 21. He also did research work in illuminating engineering. He taught Diesel Engineering in trade schools and served with the Army Transportation Corps during World War II. Having inherited the inventive spirit from his ancestors, he was always curious to know the how's and why's of basic engineering problems. He has obtained 5 patents for various engineering devices.

Man has always made progress in his struggle onward. Sometimes quite rapidly; other times very slowly. It took about 500 years for man to develop a point on the Archimedes Screw, and almost 2000 years for him to develop Heron's Eolipile into what we now consider as our modern jet engine. For over 400 years we have been giving up heat B.T.U.'s (Power) to the cooling system of our Steam Power Plants for the price of conserving the Spent Steam condensate and a small gain in power. This loss of B.T.U.'s (Power) has been taken for granted in an all too common way.

In my early days of engineering training the Diesel Engine was the major interest in my mind, even if the diesel engine did lose a lot of B.T.U.'s by exhausting the burnt gases before all the heat was recovered. At that time it looked as if the Diesel engine would eventually displace all the Steam engines. Of course there were a few engineers whom I thought were "diehards," who did not think the same way I did and their remarks caused me to ponder about the loss of heat by the Steam engine. It was quite plain that if man was to progress further along this line of engineering it was necessary for someone to discover a means for conserving the B.T.U.'s (Power) lost by the Steam Power Plant's Condensing System.

At the beginning of my Engineering career the Steam Turbine and pipe boilers (generators) were still in their early stages of development, and were

looked upon by some persons with skepticism. At that time manufacturers of Diesel engines were endeavoring to publicize the superior features of their engines over the old engines, and those advocators of the Diesel engines used every opportunity to stress that there was considerable loss of heat B.T.U.'s in the process of condensing the spent steam into water. In order to return the spent steam to the generator it was and is still necessary to use a condensor, as no machine is available that will return the spent steam to the generator without first forming a condensate. There is, however, always the necessity of conserving the treated fresh water, especially aboard ships.

I kept this problem alive in my mind for many years, and whenever I visited any of the larger steam power plants, whether marine or stationary, I took every chance to inquire about the condensing system. For a long time I made no progress and charged my curiosity and aspirations to my miserly thoughts of the B.T.U.'s that were being lost by our heat engines. I even made a research to find out the value of the fuel being used by the steam generators in the United States. I learned that if a 50 percent saving in fuel could be made it would amount to about two-and-a-half billion dollars per year. Besides, the railroads would be able to make great savings. This caused me to carefully explore every reason of why the various designs of pumps and other machines could not return the spent steam to the generator without first making a condensate out of the spent steam. By the logic of common reasoning it became apparent that somewhere there was hidden a basic answer to the problem.

I gradually became more intrigued by the great amount of heat that was lost or transferred to the condensor cooling water. To satisfy my growing interest of that loss I intended my inspection trips to include the engine rooms of the boats, and with a little bosh I learned the whys and wherefores of such a heat loss in the condensor. This caused me to think that there was no apparent reason for condensing the spent steam other than to conserve the treated fresh water, because most of the power that was gained by the vacuum obtained was consumed by the necessary condensor machinery.

I had used the simple fundamentals of physics in developing a glareless auto headlight, so why wouldn't the same general principles of reasoning be a means for discovering a method to return spent steam to the steam generators. I learned that the basic and most convenient fundamentals were those created in the atmosphere of the Earth. To observe or study the pressures in the atmosphere that was comparable to those of the spent steam from a steam turbine, it was necessary to learn what was taking place at about the 60,000 ft. altitude or stratosphere. That research revealed to me that there could be useful phenomena taking place even at the lower altitudes that could be encompassing the secrets, for the means I was looking for. It was apparent that those phenomena would provide the answer for the means of returning the spent steam to the generator.

By a research in meteorology I became reassured by the old recorded facts that a cloud was only a general form of moisture with a percentage of electrically-charged particles (impurities) that are borne by an intermixture of air currents. I also found that the phenomena in the lower altitudes were also affected by changes in temperatures or pressure, or both. These phenomena are triggered by electrical-charge, chain thermal mechanism, or nuclei action, that causes the clouds to condense into a form of moisture that grows and is overcome by the force of gravity, and falls to the Earth as a heavy fog,

rain, snow or hail. It is known that water must have a catalysis or hygroscopic nuclei to freeze at 32 deegres F. By the same logic water vapor (spent steam) also must have about the same character of nuclei to cause the saturation to grow into a liquid. In all cases the growth is stimulated by the electrically-charged particles and the chain thermal mechanism that cause an increase in the affinity of the molecules.

By the same logic the steam accumulator system is based upon the fact that when heated water is relieved of the pressure that is maintained upon it, the heated water will change into a vapor (steam). The heated water will continue to become vapor until there is a temperature, pressure balance. Therefore it is reasonable to assume that a reversal of the above can be made to take place by the application of pressure. The desired transmutation is also aided by the phenomena in chain thermal mechanism of the electrical-charged hygroscopic nuclei, affinity of the moisture molecules and the thermo-inertia of the vapors. This action causes the water vapor molecules to implode into a liquid which causes a chain-chemical attraction (affinity).

We are now using the temperature method for forming a condensate out of the spent steam of the steam engine. This method is possible as it uses pressure and a temperature change by conviction which promotes the chain thermal mechanism to affect the stability of the moisture molecules. That in turn implodes into a stable liquid (condensate). Every condensor is subject to the vapor molecules implosions and the action is confirmed by the surface decomposition of the condensor tubes and other exposed metal that promotes the implosion of the moisture molecules.

We know there are mechanisms that have small nuclei that will produce by decomposition implosions or explosions, and that are governed by the surrounding properties of the system. Such implosions are called thermal implosions. The theoretical treatment of the conditions involved were first made known by van't Hoff (1884) and reexamined by Frank-Kamenetski (1939) and Rice (1940) and used by Robertson (1947) to explosions in the condensed phase. Ideas concerning the size of the nucleus of decomposition for developing explosions and implosions have been obtained. It was found that the basis of the theory occurs due to the self-heating and self-cooling, stimulated by the conditions of the surrounding nucleus.

The above are common characteristics of those of the Earth's atmosphere where nature processes the clouds (water vapor) to form a condensate in the form of heavy fog, rain, snow or hail. Likewise by the above logic there are definite possibilities in using a pressure method for causing the transmutation of the spent steam into a liquid, as the pressure method will also be aided by the natural phenomena of electrical-charged hygroscopic nuclei, thermo-inertia, chemical affinities and chain thermal mechanism.

I do not want it to be assumed that I infer in a 100% manner that whatever nature does so can man also accomplish. Some of the scientists and engineers have of late years entered into a push-button electrotechnics of calculating that nature can be seduced to reveal the secrets of her phenomena in order that we can convert them to our use. This has caused all too many reasons to be mentioned here, as to why our present-day machinery can not be used to return the spent steam to the steam generator without first forming a condensate. In my research of meteorology, vapor molecules, hydraulic dynamics, hygroscopic nuclei, and chain-thermal mechanism and

mechanical engineering, I have been led to believe that it is possible by the expenditure of time and money for further research, to design a machine that will return the spent steam (vapor) to the generator without the necessity of a condensor. We have followed an easy road and taken the condensor losses for granted as hereto it was always thought that those losses were not recoverable. Therefore, it was thought that such losses could not be avoided. To increase the steam generator's efficiency we have learned that it is necessary to return the spent steam or exhausted steam to the generator as hot as possible, until now the spent steam has to be first changed into water in order that the present day machinery (pumps) can return the spent steam to the generator.

A machine that will return the spent steam to the steam generator will conserve those B.T.U.'s which I miserly think as being lost, and will cause an increase in the steam generator's efficiency that in turn will make possible great saving in fuel, that will more than justify the efforts and the money expended in further development of such a machine.

THE FUTURE OF PLASTICS IN ENGINEERING

ACKNOWLEDGMENT

This article is an abridged version of a lecture delivered at the Plastics Institute on November 13, 1952, by Mr. J. E. GORDON. It was published in the November 28 and December 12, 1952 isues of "Engineering."

Present-day engineers have built for themselves an age of "Meccano." They think in terms of fabricating all kinds of structures from sheets, angles, etc. This leads to a very inconvenient division of labor, for it is the duty of the metallurgists to produce these sheets and angles, after which they hand them over to the engineer who builds whatever he can from the "Meccano" parts available. Though many engineers would deny it, this way of thinking is deeply ingrained in the engineering outlook and it is going to take a great deal of hard work to get rid of it. Of course, for many purposes the "Meccano system" is very convenient, but I would suggest that a limit of development along those lines is almost in sight.

During the war, when I was serving on a committee to encourage the use of plastics in aircraft structures, we circularized the leading aircraft designers and asked them what properties they would like to have in a plastic for aircraft construction. Without exception the replies indicated that they would like a material very like Duralumin, but rather better, if possible, which could be used in the same way. I do not think that it is technically possible to produce a "plastic metal," and even if it were, it is difficult to see any object in doing so. It is, perhaps the combination of the two factors—high efficiency and cheapness—which is, I hope, going to enable some real advances to be made in engineering. Because, with this "Meccano system," it is convenient to make rectangular objects, the engineer perhaps assumes that rectangular shapes are those which it is desirable to make.

There is another aspect of the problem. It suits our present system of dividing labor and responsibilities for one man to design the structure and for others to add the wiring, plumbing and the internal and external finishes more or less as afterthoughts. In plastics, of course, we have the possibility of combining all these into one integrated structure, with great improvements in cost and efficiency. However, the amount of human coordination required is certainly frightening. This question of the efficiency of shape and function is a very real one. Engineers tend to compare materials by simple mechanical properties such as tensile strength, and in a "Meccano" structure this is generally

fair and correct. In some aircraft structure, however, we tend to find that it is not at all an adequate criterion. Comparing, say, Duralumin and Durestos simply as materials, you must come to the conclusion that Durestos is only about half as efficient as Duralumin. On the other hand, since, by being cunning you can make structures from Durestos which are about as efficient as Duralumin structures, it follows that the efficiency of shape in the plastic structure must be something like twice as high as that of the "Meccano" component.

To both the layman and the engineer the whole idea of plastics has somehow become associated with lightly-stressed and relatively trivial uses. The prospect of putting really large loads upon apparently fragile plastic structures is felt to be wrong. Even when one has worked on the subject for quite a long time and is familiar with the calculations and the stresses involved, one feels "It cannot possibly take such loads." Of course, there are many failures, but generally these devices do take the loads expected of them. We have to demonstrate that this subjective feeling is wrong, both to ourselves and to others. Nevertheless, the mechanical properties of plastics are important. Though for many purposes we have quite adequate strength and stiffness already, there are quite a number of applications where we should like better materials. For a long time to come we shall have to depend on reinforced plastics for high-strength applications. Considering reinforcing fibers, we should do well to banish cellulose as far as possible, at least until its moisture response can be much better controlled. At present we have only glass and asbestos as relatively inert and strong reinforcements. There may be other fibers which exist or can be made. Both silica glass and crocidolite asbestos seem to promise the possibility of much higher strengths.

Stiffness is just as important as strength in many structures, and it has long been one of the principal defects of plastics that their stiffness compared with that of metals is too low. Fairly recently it has been found possible in the laboratory and on a small scale to make reinforced materials with a marked improvement in stiffness. Unfortunately, it has not so far been possible to combine the increased stiffness with the increased strength. However, I am quite hopeful that we shall be able to do so before long. If we succeed in making a really strong and stiff material, then it will produce at least one serious difficulty in its use. It is of no value having a more efficient material unless you can use less of it. This means that the various thicknesses will be greatly reduced and we shall encounter buckling troubles. There are, perhaps, two ways of avoiding this difficulty. The first is to introduce some kind of light-weight stabilizing material. There are a number of these, the most attractive seems to be the kind which can be poured into a cavity and will foam and set *in situ*. At present there is only one material of this kind, i.e., the Sebalkyd class of resin. It is still rather expensive, but its worst defect is that, at the moment of pouring, it is extremely poisonous and must be handled with great care. We should very much like to have a cheaper and a harmless material. Whether such a structure consists of a single closed shell filled completely with foam or whether it consists of a "sandwich" in the ordinary sense, will depend on the circumstances of the design.

In many cases, however, it would be preferable to approach the problem in a different way, that is, by reducing the specific gravity of the material. It may be that one reason why wood is so widely used, even today, is that its specific gravity is practically ideal. A timber of twice the present density would be rather an impracticable ma-

terial, yet the densities of most plastics are about twice that of most timbers. It would help the design of aircraft structures, at least, if we had a plastic with a specific gravity of about 0.5 while keeping the present specific strength and stiffness properties. The reduction in density would probably have to be achieved by incorporating air voids, as in wood; then, no doubt, we should get something like the toughness and the warm "feel" of wood.

So far, I have speculated about plastic structures as being made wholly of plastics, but I do not think there is any reason why we should not employ metals in the same way as plastics and in conjunction with them. As a simple example, one might have a pressed shell of thin sheet metal filled with a foamed plastic. Some of the more complicated examples also look promising. It is possible, for instance, to obtain good adhesion between steel and the Durestos class of materials if the two are molded together. The coefficients of thermal expansion are similar and the phenolic resin appears to inhibit corrosion in the steel. In this way, one can make Durestos shell structures with steel inserts in the more highly stressed places; the steel sheet need only be cut roughly to shape and the Durestos provides protection and a smooth finish, besides helping to stabilize the steel under compression. In this way, we may have some of the best of both worlds, having, to some extent, the strength, stiffness and low material cost of the steel combined with manufacturing cheapness and good finish of the plastic. Metals are really excellent as materials: they are cheap, strong, stiff and tough. The difficulties arise in shaping them and to some extent in stabilizing thin shells (hence corrugated iron). Going a little farther in the direction of metal construction, I should not be surprised to see a wide use for the process which has recently been developed at the Royal Aircraft Establishment whereby shaped objects are assembled from simple stepped plates of metal. The steps are then filled in with a suitable resin which can easily be finished to the required form. Another need is a really cheap and satisfactory finish for the low-pressure laminates. Perhaps the "transfer finish" system (whereby the finish is sprayed on the mold and transfers itself to the molding) may be an answer.

All these requirements are very desirable, but I think that existing processes, imperfect as they are, would be technically quite satisfactory for a wide range of applications. One has to ask "Why do plastics seem to be catching on so slowly in engineering?" The answer is perhaps partly a question of conservatism, a reluctance to break out of the cage, and partly that many designers do not realize how much can now be done by the various new processes and their imaginations have not been caught by the armory of new devices at their disposal; yet I think the main reasons are economic. The manufacturer is frightened by the high costs of the raw materials combined with the undoubted technical difficulties. The economic question is very complex and must depend on the type of product. Let us examine a few concrete examples and hazard some actual costs.

APPLICATION TO AIRCRAFT

There are some parts of aircraft, such as "radomes," where plastics are essential for technical reasons, and there are others, such as internal equipment, where plastics have proved cheaper and lighter than metals, but with the main structure of the aircraft the position is different. If we consider the airframe of a transport machine, the all-important consideration is weight. A pound of weight saved on the airframe is a pound of extra pay-load throughout the

life of the machine, and that is worth a great deal of money. With existing materials it is difficult to promise any considerable saving of weight over a metal airframe; relatively small improvements in materials, however, might put the question in quite a different light. If that were so, the cost of the material would be a secondary consideration. The design and manufacture of a transport aircraft, however, is an enormously difficult and expensive project and it is unlikely to be undertaken in plastics until there is ample successful experience with small light aircraft. Leaving aside military airplanes, this experience is most likely to be gained on the light "private owner" type of machine. I believe that the cost of building conventional airframes is in the region of 50*s*. per lb. of finished weight, the cost of Duralumin is about 3*s*. per lb., the difference being mainly cost of fabrication. Since the weight of the airframe of a two-seater aircraft will not be less than about 600 lb., one is faced with an expenditure of about 1500*l*. before providing an engine and instruments.

If the cost is to be reduced sufficiently to justify quantity production the total price must be cut substantially. Most of this reduction must be at the expense of the airframe because the engine and instruments probably cannot be very greatly cheapened. To make the venture attractive, therefore, the target to be aimed at seems to be a structure cost between 10*s*. and 15*s*. per lb. This might reduce the airframe cost to 300*l*. or 400*l*., and take 1000*l*., or so, off the cost of the aircraft.

This probably requires a material cost of, say, 5*s*. to 7*s*. per lb. at the most, and there are structural plastics available at these prices which are technically suitable. A difficulty arises out of the low wing loadings which are necessary. These lead to low structure loadings and thus to thin panels of material which need to be stabilized, probably by a foamed material. If this is to be of the foamed *in situ* type, it will cost about 15*s*. per lb. Such a project might, therefore, be regarded as just about marginal at present, a relatively small reduction in cost might make it economically attractive. Technically, I do not think there are any insuperable difficulties, and there are some considerable advantages. For some time aerodynamicists have had available wing sections of much lower drag, if only smooth surfaces could be attained; if we can get these smooth surfaces with plastics we shall see a much better performance. Again, a considerable part of the cost of running an aircraft arises because the law rightly requires that the complex structure shall be pulled to pieces and examined at fairly frequent intervals in the interests of safety. In a plastic aircraft this should not be so necessary as there will be very little to examine; moreover, fatigue is unlikely to be a serious trouble.

APPLICATION TO MOTOR-CAR BODIES

If we take the cheaper end of the scale, say a motor car, then, superficially, the present position appears to be much less favorable. If the cost of a car body is about 4*s*. per lb., the existing laminates would seem to be out of the market altogether. On the other hand, one is not so much purchasing weight as strength. If we could replace 18-s.w.g. steel by 0.10-in. laminate, then the weight of the body would be roughly halved and we might afford to pay about 8*s*. per lb. for the finished body. If such a weight could be achieved then reductions could be made in the engine and chassis and an altogether cheaper car might result. While a steel body is relatively cheap, it is heavy, and because

it rusts its life may well be shorter than that of the chassis and engine. At 8*s.* per lb. finished weight, the existing laminates are still too expensive, but if we suppose a suitable cheap material to be available it is interesting to inquire how the job might be tackled.

It is clear that much re-design would be needed. One of the objections which is often raised to the plastic car body is that it would be difficult to repair. However, we might consider such a body as being molded in comparatively small panels, not more than 2 ft. or 3 ft. square. These panels might be fairly readily detachable and their joints might be concealed by a plated beading. Each panel might comprise the outer finish, the structural shell, much of the inner finish and possibly certain wiring and fittings, all molded in one operation. Replacement panels might be sold so that a damaged unit could be replaced by undoing a few bolts; this might be a much quicker and cheaper form of repair than the present system of panel-beating followed by re-cellulosing. For the quantities involved the present low-pressure laminating processes are probably not economic and it seems probable that pressure-molding with metal dies would have to be used.

This raises the question of the curing cycle. Judging by American experience, it is possible to reduce the cure times of the glass-polyester materials in heated dies to a matter of two or three minutes or possibly less. Unfortunately, the glass-polyester materials do not, at the moment, seem to promise low enough material costs. If we want a cheap material we shall probably have to use a phenolic resin. The cure of phenolics by normal methods seems likely to be too slow for a process of this type. At Farnborough, however, we have been developing an electrical curing system which gives virtually instantaneous cure and it seems likely to give production rates equivalent to those attained with steel pressings. Incidentally, I wonder whether wings and bumpers in polyethylene would be practicable. They would be very light and virtually indestructible. Several designers have said that, if they could only obtain a phenolic felted material for less than 2*s.* per lb. the uses to which it could be put would be virtually unlimited. This, of course, is far less than present prices, but not an impossible target. There is a circle of cause and effect in such matters which is difficult to break. Because there is no cheap material on the market there is no firm demand for it, and because there is no firm demand there is no supply, for such prices can only be attained with large-scale production.

It is at this stage that many people raise the argument about the supply of basic raw materials. It is difficult to be dogmatic, yet it seems to have been the general experience in the past that, if the demand is loud and clear, the raw materials will be found, and often at a surprisingly low price. The difficulty probably lies in the delays which accompany the provision of new plant and equipment. The production of shell structures at low cost is something that plastics can do well, given quite a modest reduction in material costs. It is just this making of shaped shells that is so difficult and unsatisfactory in metals. Apart from the lighter types of shell structures, there seems to be a potential opening for piping and containers in chemical works, gas works, oil refineries, etc.; and the fact that it is easy to make such shapes may lead to the development of new kinds of products.

I do not see why plastics should not play a part in mechanical engineering. For instance, if we are ever to have really cheap gas turbines for general use in cars and for similar purposes, we must get away from the position where hundreds of very expensive metal blades have to be attached separately to an elaborately machined rotor. We cannot undertake actual turbine blades

—we may have to leave these to those cousins of plastics, ceramics—yet the actual turbine is generally less of a problem, economically, than the compressor, especially the axial-flow compressor, in which a moderate improvement in heat resistance may enable us to mold complete rings of blades integrally with their discs. This is an application where the cost of the material is secondary to its performance. Even in established fields there may be an opening; e.g., it should be possible to make road wheels, calender bowls for the paper and textile trades, and many other devices.

All these applications are in the field of orthodox "rigid" engineering. With plastics we have, for the first time, a really remarkable range of flexible materials and it may be that one of the most interesting prospects will be the opening up of new engineering in flexible materials. There are some obvious uses for flexible piping, etc., but we hardly begin to touch the possibilities of what I might call "pneumatic" structures. We have heard relatively little in this country about the "air-supported roof," though I believe it is being exploited in America. A very large, flexible, and preferably transparent, sheet of plastic is spread out and "pegged down" at the edges. Small fans are then used to blow the sheet up into a saucer-like roof; little pressure is needed. Such domes are quite stable in high winds and can withstand snow loading. If they are successful they will open up quite a new approach to the question of weather protection.

If we look still farther ahead the prospects for the future are bewildering. Consider, for instance, the possibilities of a really satisfactory photocatalyzed material. One can imagine that such a material might be set by a process akin to three-dimensional photography. Instead of expensive molds one might feed the necessary optical scanning data into a machine by means of a punched card and thus obtain any shape we care to demand. Again, there is the possibility of a soft piezo-electric material. An animal can be considered as both soft and infinitely rigid, for it can resist a deflecting force, without displacement, by pushing in the opposite direction, consciously or subconsciously. If we had a material which could be made to expand or contract by a small amount by applying an electrical potential the whole approach to structural engineering would be altered.

It would be absurd to pretend that plastics are ever likely to oust metals completely and it may be that they will always be in a minority as regards tonnage. It must be remembered that enormous quantities of wood are used today, perhaps more than metal, and certainly more than was used in 1800. The coming of metals, however, transformed engineering by transforming people's ideas, and we may find plastics acting in a similar way as a catalyst for a new Industrial Revolution. Are we going to take the lead in this process or abandon it to some other nation? We must spend more on development work. Yet money without men is useless; we must seek to attract the right kind of men. Scientists we must have, of course, but I do not think that we need only, or mainly, scientists. The trouble with scientists is that they do not recognize that engineering is not really a science; it would be easy, and rather malicious, to compile an anthology of "howlers" perpetuated by eminent scientists. Engineering development is not a science—at least not in its early stages; it uses science, which is a different matter, just as does medicine. One of the great Eighteenth Century doctors was said to have "found Medicine a Trade and left it a Philosophy." Perhaps we need men who will be both adventurers and philosophers in engineering.

GENERAL CONSIDERATIONS IN NAVAL SHIPBOARD POWER MACHINERY DEVELOPMENT

IRWIN E. JACKSON, JR.

THE AUTHOR

IRWIN E. JACKSON, JR. received a B.S. degree in Mechanical Engineering from the Pennsylvania State College in 1934. Prior to his appointment as an engineer in the Bureau of Ships in 1941, he was engaged in public utility valuation and rate regulation, design and construction of transit facilities, and private housing construction. He also served as law clerk in the office of an attorney who was directing the development of a large private housing project. Mr. Jackson completed an M.A. degree in Mathematics at the University of Pennsylvania (1936) and the graduate professional degree of Mechanical Engineer (1941) at the Pennsylvania State College. From 1941 to 1943, he worked on engineering performance analysis in the Research Branch of the Bureau of Ships. Following service as an Air Force engineering officer from 1943 to early 1946, he returned to the Bureau of Ships in his former position. He became a member of the Gas Turbine activity in the Bureau of Ships Technical Division in late 1946, and since that time has been engaged in the development of gas turbine plants for naval applications.

Mr. Jackson has written several Bureau of Ships publications on gas turbines and ship performance. He is a member of Pi Tau Sigma, national honor society in mechanical engineering.

World War II has been responsible for a sharp increase in emphasis on research and development in relation to national defense. Concrete evidence of this trend is the creation of the Research and Development Board on the highest policy level in the Department of Defense and similar significant structural changes within the Departments of the Army, Navy, and Air Force. Examples on this level are the Office of Naval Research and the Air Research and Development Command. Within the Navy Department the various Bureaus have created their own research and development offices. An example is the Assistant Chief of the Bureau of Ships for Research and Development. Some fundamental questions arise in connection with these activities. What is research? What is development? Are they essential to national defense? If so, why? What is being done to meet the research and development needs of national defense? Are the programs of the various agencies properly planned and prosecuted? Is there a guiding policy with adequate control and coordination or

simply a variety of un-coordinated efforts in several directions? These and other questions are considered in the following discussion with respect to the development of power plants for naval shipboard applications. Primary consideration will be given to the role of the Navy Department although the responsibility for improving the quality of naval power plants rests jointly on the power plant manufacturing industry and the Navy. The importance of the line on a football team is not decreased because the attention of the spectators is on the backfield.

A continual expansion in the number and variety of necessary jobs done in naval vessels by power machinery has taken place since the creation of the Bureau of Steam Engineering in 1862, ninety years ago. The importance of these functions in the overall operation of naval vessels is obvious, and it follows necessarily that satisfactory operation, maintenance, repair, and supply of all units in service is essential to the continued existence of the Fleet. It is not so clearly evident that a continuous development program is required to complement these activities. Naval service requirements place heavy emphasis on reliability, which encourages a dubious attitude toward machinery of new or different design. A healthy, open-minded skepticism is good. This attitude requires substantial proof of the merits of a new or improved unit, but leaves open the possibility of replacement of existing units by later designs of improved characteristics.

A dogmatic attitude produced by an overemphasis on reliability closes the door to development and ultimately leads to obsolete equipment. At the other extreme lies the attitude which insists on building machinery based on visionary schemes which offer extremely attractive theoretical advantages but completely ignore the practical problems involved in translating theoretical promise into actual machinery performance. The responsibility for making this translation rests upon, and must be accepted by, those in charge of the development work. Since neither extreme position is desirable, power plant development policy must steer a course between them. Objectives must be set which are attainable within reasonable time, cost, and manpower requirements. At the same time, these objectives must include sufficient advances over existing engines to justify the cost of development.

Some assistance in visualizing the development status of a machine or system is given by the use of a concept, which may be called potential-reliability-usefulness (PRU) curves, as follows.

The graphs represent two sides of the basic problem of machinery development, and are applicable either to prime movers, complete systems, or components. Every basic power plant design may be assigned a maximum potential in terms of its performance characteristics, present and future, when the first prototype tests are run. At this point in its development, the machine will incorporate some of its maximum performance potential, which we may call "used potential." The balance may be called "unused potential," which may be converted into "used potential" through further development of the basic machine design. This concept is shown on Figure 1(a). Points P_1 and Q_1 represent the status of a power plant in an early stage of development, in which its potential is largely unused. P_2 and Q_2 represent a later stage at which more of the maximum performance potential has been realized as used potential, but a considerable amount of unused potential remains. Further development of the engine may be productive of results. P_3 and Q_3 represent the stage at which practically all of the originally unused potential has been realized in the actual machine. Further

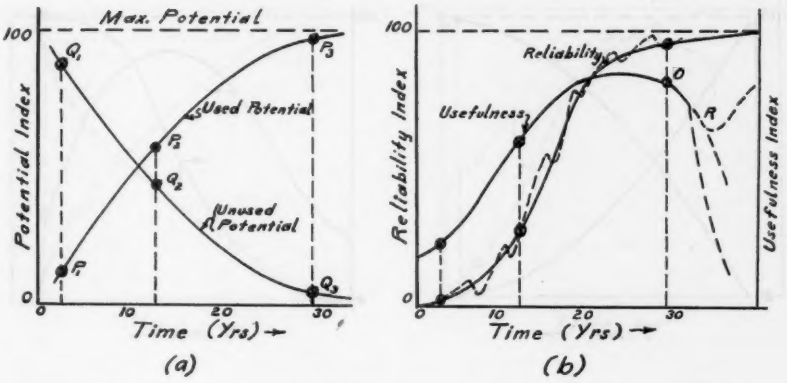

Fig. 1

development is unproductive, and the machine is obsolescent. When a proposed development can be identified with either of these extreme positions on a PRU representation, i.e. (P_1 Q_1) or (P_3 Q_3), a decision can be made without difficulty. The usual situation involves an intermediate status (P_2 Q_2) which requires further study.

Reliability is also a function of time, since accumulated test and service experience are the only means by which reliability can be determined and by which the causes of unreliable operation may be isolated and corrected. In this respect, all new developments start with zero reliability. The solid reliability line of Figure 1(b) is an average line, whereas the dashed line oscillating about the solid line shows the actual variation with allowances for the effect of changes in the basic design. Figure 1(b) also shows a curve of usefulness, which may be measured by the number of units of the given design in actual service or some similar index. This curve does not start at zero as all machines are devised either to meet some specific need for which existing machinery is not suitable or to afford improved performance over existing machinery in current applications. Point O at which usefulness begins to decline may be called the point of obsolescence. Normally the decline in use will be gradual as shown by the bell-shaped curve of Figure 1(b), but there may be a sudden decline as shown by the broken line after O. There may also be a revival of interest in a machine following a decline in use, as shown by the broken line after R. Such abrupt changes in long-time trend often result from basic inventions.

Practical illustrations of the concepts employed in Figure 1 may be shown by a consideration of some naval propulsion machinery systems. Each system may be associated with its characteristic potential curves (P-curves). The relative position of the system on its P-curves then shows its past, present, and probable future from a developmental standpoint. Reliability and usefulness curves result from experience with the system. For example, direct drive steam engine propulsion plants are fully developed, highly reliable, and declining in usefulness for naval purposes. Figure 2 is a representation of this situation.

At the other end of the development spectrum is the nuclear reactor-steam

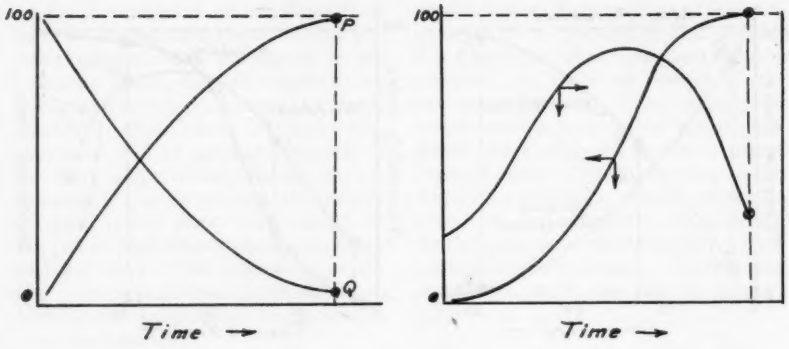

Fig. 2 PRU Curves for Direct Drive Steam Engine Naval Propulsion Plant

turbine propulsion plant. While steam turbines themselves are highly developed, highly reliable, and widely used, the unknown factors associated with the reactor-turbine combination are many. It is therefore unrealistic to rate this system at the same reliability index as the steam turbine plant having a conventional steam generating means. The generous cruising radius and other advantages promised by the nuclear propulsion plant give this system a high maximum potential, while its reliability and usefulness have not yet been established. A representation of this situation on PRU curves is shown in Figure 3.

The concept of PRU curves is intended only as an aid in development planning, by which perspective and orientation may be established. No absolute values are necessary or intended to be associated with the curves. For example, gas turbine power plants do not have the same absolute maximum potential as nuclear power plants due to the superior promised advantages of nuclear fuels. However, both power plants have a relative maximum potential of 100 from the standpoint of full utilization of their respective inherent performance capabilities. Consequently two different machines cannot be compared on the same PRU representation without scale modification.

When reliability is assigned its proper place and relative weight, by the PRU concept or some other device, the justification for a continuous naval machinery development program is easily seen. Reliability is a quality which, like vibration prevention, can only be partially designed into a prototype machine, at least in the present "state of the art." There is an unavoidable unknown factor in any development which represents an appreciable variation from the conventional, otherwise the variation is not really a development. In this sense, development and reliability are contradictory, but only temporarily. In other words, a complete cycle of development

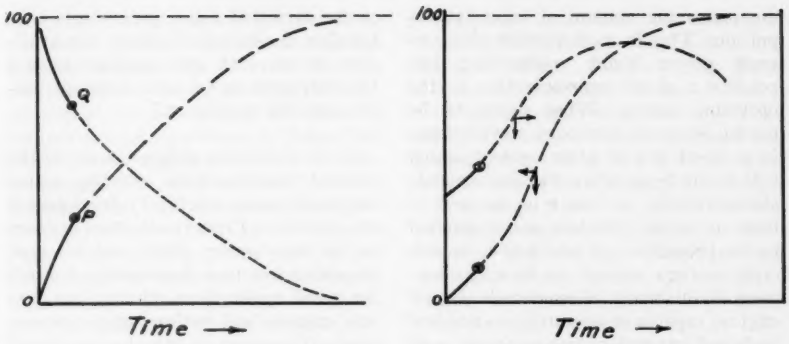

Fig.3 PRU Curves for Nuclear Reactor-Steam Turbine Naval Propulsion Plant

includes the proof-testing and modifications required to obtain the essential degree of reliability in the product. An additional responsibility rests on the development engineer if the improved characteristics are to be preserved. This task is the preparation of plans and specifications which will insure against wide variation between the production version and the prototype.

The benefits derived from a machinery development program are not all direct, and therefore are not necessarily measurable by the value of the development product. A "side reaction" usually occurs in competing machinery types when advances are made in a specific machine. The advent of a new prime mover always accelerates the improvement of existing engines, particularly when the new prime mover begins to displace existing machinery in various applications. For example, the challenge of increased use of diesel power in locomotives spurred an intensive effort to improve the performance of locomotive steam power plants. A similar reaction in the aircraft reciprocating engine industry was initiated by the advent of turbojet and turboprop engines. The challenge of gas turbine engines for marine applications has likewise stimulated increased efforts to improve marine diesel power plants, particularly with respect to the burning of residual fuels and the reduction of engine specific weight.

The ultimate objective of a development program for naval shipboard power plants is to provide the optimum machinery installation for each of the various types of ships (i.e., DD, CA, CV, SS, etc.). A discussion of these ideal characteristics and the respects in which various prime movers approach or fall short of them would be of little practical value. It is easily seen, however, that none of the power plants now in service can be considered the optimum power plant for all types of ships. While the turbojet aircraft engine is perhaps not the ultimate aircraft power plant, no naval shipboard prime mover dominates its field to the extent that the turbojet

dominates the domain of aircraft propulsion. This is an indication that aircraft power plant engineering has reached a closer approximation to the optimum engine. What seems to be needed in naval shipboard power plants is a novel power plant system which will radically improve the performance characteristics of one type or several types of ships. Nuclear power applied to the propulsion of submarines or aircraft carriers appears to be a development of this order of magnitude. Diesel engines capable of operating on residual fuels and gas turbine power plants, with the proper additional development, also offer considerable promise in this direction. As recently as January, 1949, a former Engineer-in-Chief of the British Fleet stated that apart from the gas turbine there had been no outstanding change in the last twenty-five years in the types of propulsion machinery in use in warships, although appreciable advances had been made with respect to conventional types. (1) The same author also noted that "Perhaps the greatest advance has been in the recognition of the fact that rapid progress is only possible if adequate facilities are available for research and development and for shore-testing of new types of machinery and equipment."

In the following sections, some of the general considerations affecting naval shipboard power machinery development are examined. Primary attention is given to the two power plant systems now absorbing the most developmental effort for naval applications, namely gas turbine engines and nuclear reactor power plants. Constructive criticism is offered concerning the effectiveness of the organization and procedures by which the Navy Department prosecutes power plant development. These comments are not intended to deny the past accomplishment or usefulness of the system now in use, but to stimulate thinking toward its improvement. Effective engineering management within the Navy Department is essential to the attainment of the objectives of naval shipboard power plant development with the minimum expenditure of funds, time, and effort.

NATURE OF DEVELOPMENT WORK

Development is a word of many meanings. It is used with shifting connotations which vary greatly among technical and scientific authors and speakers. Development is often confused with such terms as research, pure research, basic research, applied research, and invention. In the interest of clarity, the following meanings will be understood in this discussion.

Pure or Basic Research—Investigations involving the extension of knowledge for its own sake, with no specified objective or necessary application.

Applied Research — Investigations involving the extension of knowledge in a particular direction for a specified purpose or application.

Development — Investigations directed toward the satisfaction of an immediate practical need by application of the results of pure or applied research, invention, or other means.

Invention—The act of devising and reducing to practice a new method, process, machine, material, or improvement in the same.

Development is thus seen to be primarily a technological function involving those skills usually regarded as engineering skills. Research is normally considered a scientific activity to be performed by mathematicians, physicists, chemists, etc., rather than engineers. Of course, engineers may perform research tasks and scientists may do development work, but ordinarily the training of a scientist is not adequate preparation for

the tasks associated with development nor does normal engineering training prepare engineers to do research. An illustration may be drawn from the field of atomic energy. In the evolution of nuclear reactors, primary emphasis has shifted from applied research to development. The early reactors were designed, built, and operated under the direction of scientists like Dr. Enrico Fermi, who had also participated in the basic research upon which the designs were based. These reactors were admirably sufficient for the purpose for which they were built, namely, the production of fissionable material of acceptable purity. However, these early units were not economical "engineered" reactor designs, nor were they expected to be. When nuclear power began to receive serious consideration at the end of World War II, the questions of reactor efficiency and cost took on major importance. At this point it was decided to initiate training courses in nuclear science and engineering to provide a body of technicians capable of carrying out reactor development. In other words, it was desired to apply the engineering approach to this work on the foundation of research already carried out by the scientists. The training of a scientist is not generally adequate to the task of producing economical designs, while the training of an engineer is not generally adequate to the task of formulating new scientific principles and exploring the broad consequences of those principles.

The above remarks apply to power plant development in general and to naval power machinery in particular. Consider the problem of utilizing modern land power station steam conditions on shipboard. This is an engineering problem with the objective of producing a steam power plant of improved performance without appreciable sacrifice in other essential characteristics for naval applications. This objective must be attained within reasonable (or at least ascertainable) time and cost estimates. Design full power steam conditions must therefore be so established that there will be no "snowball effect," that is to say there will be no possibility of one or more sub-projects outgrowing the project itself. For example, steam conditions requiring the use of turbine blading materials on which metallurgical knowledge is inadequate must be avoided unless extreme latitude can be allowed on cost, delivery, and testing. Otherwise the investigations required to obtain a satisfactory set of turbine blades from these materials may mushroom into a full-size metallurgical research problem. Engineering judgment must therefore be exercised in the planning and design stage of a machinery development in the establishment of objectives which are realistic from the engineer's point of view rather than from the scientist's viewpoint. As the basis for such decisions, it is necessary that the engineer have at hand adequate information on the current state of the art not only in power plant development but in related research (i.e. physics, chemistry, and metallurgy of materials, chemistry of fuels, etc.)

The development engineer, therefore, must be conversant with basic and applied research insofar as the needs of the project in which he is engaged require him to make recommendations and decisions on questions involving research. On the other hand, he cannot permit himself to be submerged below periscope depth by research problems incidental to the accomplishment of the main development objective. It is evident that the nature of development work requires that the successful development engineer possess something more than the standard professional engineering equipment, at least on the level of responsible charge. This additional equipment is not necessarily synonymous with formal postgraduate degrees, but does necessarily include an open mind and a capacity to absorb and evaluate new ideas.

Since development is directed toward the meeting of practical needs, the success or failure of development projects is usually measured by a very concrete standard. If the product reasonably meets the need the project is a success, otherwise it is a failure. Power plant development is costly and is usually a long-run proposition, therefore the continued support of projects in this field frequently depends upon the production of interim results which point to a successful conclusion. The use of phase-type or task-order development contracts, in which the prosecution of each subsequent phase is made contingent upon the successful completion of the prior phase, recognizes this dependence on both interim and final results. Such contracts permit the abandonment of work which fails to show promising results and facilitate the conservation of development funds by the transfer of unexpended balances to more productive uses. Indeed, the prosecution of development projects involves decisions on contractual policy and procedure which may be of equal importance to the technical decisions. Government contracting for research and development is a topic of sufficient importance and scope to warrant an extended discussion. However, it will be sufficient for the immediate purpose to note that

a. Development engineers need a working knowledge of the applicable contractual policies and procedures

b. Development work requires a continuing evaluation of progress which may be secured under the proper contractual arrangements

c. It is advisable to require successful interim results as a prerequisite to continued support of the work.

A word of warning is necessary, at this point, concerning the nature of development work. It is not an uncommon occurrence, in both applied research and development programs for defense purposes, for participating scientists and engineers to bring forth new devices of ever-increasing complexity without sufficient consideration of the ultimate "consumers" who have to use the "gadgets." Increased attention is now being given to the question of complexity by all the services. (2) Captain J. E. Hamilton has discussed some problems arising from the growing complexity and cost of naval vessels and their equipment. (3) Neither applied research nor development should be allowed to degenerate into mere "gadgetry." Power plants and weapons are peculiarly sensitive to this malady, therefore due care must be exercised in order to avoid unnecessary complexity in these important areas of defense research and development.

Increased attention and recognition is being given to the techniques variously known as operations research, operations analysis, or operations evaluation. These methods finally boil down to the utilization of all known scientific techniques as tools in solving a specific problem in order to provide a basis for executive or military decisions. (4) The methods are applicable to industrial as well as military situations, and are now being used as a tool for development planning in the U.S. Air Force. (5) Operations evaluation emphasizes the viewpoint of the user or consumer, and as applied to naval vessel development, reflects the suitability of the ships and equipment supplied by the material Bureaus to the needs of the operating forces afloat. Analysis of the use, performance, and reliability of naval power plants under service conditions is a form of operations evaluation. The results of such analysis may be used not only to improve operating procedures with existing machinery but also to indicate directions of profitable machinery development. These methods are a useful tool in the management of power plant development.

THE NAVY'S ROLE

Active participation by the Navy Department in power plant development arises from its procurement functions since practically all shipboard prime movers and their components are purchased from private industry. Consequently, the Navy's role is primarily that of furnishing direction and support to commercial firms in order to insure the satisfaction of naval requirements. Power plant development would go on without the support of the Navy Department and the Navy would profit eventually by such development through the availability of improved engines. Unfortunately, the special requirements of naval service are such that power plants developed for non-naval applications are not generally suitable for naval service without modifications which may require a substantial program of further development. Comparable situations exist in various degrees in other industries (e.g., aircraft, chemical, electronics, etc.) as to the adaptability of their commercial products to the needs of national defense. Special situations require that the government establish its own production facilities, as is done for many ordnance items. In other cases, a standard commercial product may be entirely satisfactory for military or naval use without change. The procurement roles of the defense agencies vary consequently over a wide range, with a corresponding variation in their respective development roles.

In order to discharge its responsibilities for the direction and support of naval shipboard power plant development, the Navy Department is required to perform certain essential functions. The Bureau of Ships carries the major burden of these duties with assistance from the Naval Engineering Experiment Station (EES), the Naval Boiler and Turbine Laboratory (NBTL), the Operational Development Forces (OpDEVFOR) and the Office of Naval Research (ONR). At various times, important contributions have also been made by the Naval Research Laboratory and the National Bureau of Standards. These essential functions include—

1. A continuing survey of current power plant development progress and screening of such items to determine possible applications to naval shipboard service.
2. Determination and specification of those power plant requirements of current or anticipated construction programs in which development is necessary or desirable.
3. Initiation of development projects directed toward the satisfaction of the requirements determined in (2).
4. Direction of projects initiated under (3).
5. Preliminary evaluation of new and improved power plants developed under (4).
6. Direction of transition from development to production on successful prototypes.
7. Establishment of adequate familiarization and training programs for ship and yard personnel to insure proper operation, maintenance, and repair of developed power plants in fleet service.
8. Evaluation of power plant performance and reliability under shipboard service conditions.
9. Application of the results of experience obtained under (5) and (8) to subsequent power plant design and development.
10. Establishment of practical and workable contractual policies for the initiation and administration of development contracts, including fiscal control and patent protection.

11. Coordination and integration of shipboard power plant development with overall research and development for the improvement of naval ships and equipment.

In brief, the role of the Navy Department is to know what engine builders and their materials suppliers are doing to improve their products; to determine which of these improvements may be useful in shipboard service; to develop those items selected for shipboard application sufficiently far to assure subtantial compliance with naval requirements; to integrate the selected items into the procurement cycle after a preliminary evaluation; to continue the evaluation and improvement of these items as long as they remain in service use; and to replace them with better units when these become available. It is also the Navy's responsibility to initiate and prosecute essential power plant and related materials development in its own facilities where industry cannot or has not done so.

It is evident that engineering management occupies a central role in the Navy Department's prosecution of shipboard power plant development. Effective performance of the essential functions described above requires effective engineering management, which in turn requires the following elements (6)—

1. Known objectives and policies supported by an adequate budget.
2. Suitable organization structure with definition of responsibilities and authority.
3. Staffing of positions with engineers of adequate capacity and training.
4. Establishment of suitable working conditions and facilities.
5. Provision of effective systems and control procedures.

Shipboard power plant development is directed by activities within the Navy Department administrative structure which also have other responsibilities, therefore the resulting management problems are more complex than those associated with a single-purpose activity. For example, the Office of Naval Research is free to investigate various research problems on a department-wide level without having to carry the burden of day-to-day operation and maintenance of ships and shore facilities. Development, on the other hand, is charged to the material Bureaus which do carry these burdens. There is consequently a constant competition within each Bureau between developmental functions and those relating to operation and maintenance. This competition extends to personnel, funds, and facilities. These conflicts can only be resolved if the administrative structure permits their resolution. An organizational set-up which incorporates the five essential elements of effective engineering management for operation and maintenance does not necessarily satisfy the needs of effective development administration.

The administrative structure of the Navy Department is the product of an evolutionary process over a long period of time. With respect to power plant development for ships, new activities have been established or new functions have been added to those of existing activities as the need arose. This is not an unusual situation either in government or industry, but the resulting organizational structure is not necessarily the most effective or the most efficient. "The structure of organizations for engineering activity is frequently developed by expedient with more than the normal tendency to mold organization to individual peronalities and idiosyncrasies and to avoid a clear delineation of responsibility and authority. Such structural weaknesses frequently are not recognized because engineering tasks get done without generating excessive friction despite the ill-defined structural relationships. However, it is unlikely that these engineering assign-

ments are being done on schedule or within the estimated limits of cost and manpower with any degree of regularity. Organizational defects are being offset by additional engineering personnel, by the particular talents of key people, and by other remedial methods."(6)

Within the Navy Department, the Bureau of Aeronautics has met the administrative conflict discussed above, as related to aircraft engines, by the establishment of an Experimental Engines Branch within its Power Plants Division. This activity performs most of the essential functions in the management of naval aircraft power plant development. The well-known rapidity of obsolescence in both airframes and aircraft engines points up the need for effective prosecution of development programs. Events which have occurred in the last ten years in naval power plant development for surface ships and submarines indicate a situation approaching that in the aircraft field. The advent of two new prime mover systems within this period has given a powerful stimulus to the entire power plant manufacturing industry. This increased tempo has placed considerable strain on the Navy Department's shipboard power plant activities with results not wholly beneficial to the Navy. In the development program for the application of gas turbine engines to shipboard use, at least a part of the delay can be attributed to administrative difficulties inherent in the organization. While there are technical problems of a serious nature remaining to be solved in the development of both gas turbine and nuclear reactor power plants for naval shipboard use, the real challenge to the Navy Department is the effective administration of these programs.

NAVAL SHIPBOARD POWER PLANT REQUIREMENTS

Many years of operating experience with different types of power plants under widely varying service conditions have produced a set of stringent requirements for successful shipboard applications. There is considerable disagreement on the relative importance of some requirements resulting from the natural tendency of specialists on each prime mover to emphasize the advantages and minimize the disadvantages of a particular engine. Diesel specialists place great importance on low fuel consumption and the attendant high cruising endurance while minimizing high specific weight, fuel restrictions, and multiplicity of units in large capacity plants. Steam turbine specialists emphasize reliability, compactness in large sizes, and smoothness of operation while minimizing plant complexity, increased warm-up time, and decreased fuel economy as compared to Diesel plants. Gas turbine proponents emphasize low machinery weight and space requirements, quick starting time, and wide choice of fuels while de-emphasizing increased fuel consumption, lack of established service life, and sensitivity to atmospheric conditions. Proper evaluation of a prime mover for a specific naval application requires that the final decision be based upon the optimum approach to the requirement for the specified job regardless of special interests and preformed opinions.

The primary requirements for the selection of naval machinery are set forth in subsection A1-C(4) of Section A1 (General Requirements) in the Navy Department General Specifications for Machinery as follows:

a. Maximum reliability.

b. Minimum space and weight.

c. Maximum accessibility for maintenance, inspection, and repair.

d. Maximum resistance to corrosive action, in particular that of moist sea air.

e. Maximum economy of operation and maintenance.

f. Satisfactory operation in inclined attitude.

g. Satisfactory operation in rough seas.

h. Satisfactory operation under vibrations of the mounting at fairly high frequencies.

i. Satisfactory operation under very heavy shock to mounting and structure.

j. Maximum interchangeability of parts.

k. Minimum number of necessary spare parts together with the best facilities for stowage and handling same when furnished.

l. Satisfactory identification of all equipment and parts for ease in accurate requisitioning from distant parts of the world.

m. Satisfactory plans and drawings with full and concise manufacturing and operating instructions.

n. Satisfactory on-board repair by naval personnel.

The relative importance assigned to the above factors for any specific application will vary. For example, a prime mover for emergency service need not have a high economy, but it must be 100% reliable and capable of quick starting. Space and weight are also highly important factors for standby units since these requirements are superimposed on those of the units for normal operation. Regardless of the peculiarities of the specific application for which a development is intended, the general requirements applicable to all shipboard machinery must be met in the long run if the development product is to find wide usage in service. In the early stages of evolution of a new power plant, its use will be restricted in proportion to the number and importance of the general requirements enumerated above in which it falls short. The development of a power plant must be so planned and executed that this yardstick does not reveal any critical defects in the prototype.

GAS TURBINE DEVELOPMENT

The development of gas turbine power plants for naval shipboard purposes has been a slow process. After more than ten years of effort, both in the United States and abroad, this prime mover has not yet found its place in fleet service. Rapid development of aircraft gas turbine engines during the same period has emphasized this slow pace by sharp contrast, and has led some early gas turbine proponents to believe that there is no place on shipboard for these prime movers in the foreseeable future. That this attitude is unduly pessimistic can be demonstrated.

The disparity between the rates of development progress and application in the two above cases is more easily explained by consideration of the engine-vehicle combinations rather than the prime movers alone. What can a gas turbine do for an airplane? What can a gas turbine do for a ship? Long before supersonic flight was realized, the radical improvement in airplane performance to be obtained by jet propulsion, as compared with piston engine-propeller drive, was appreciated. A jet-propelled airplane is an entirely different airplane with respect to the important characteristic of maximum speed. No equally revolutionary improvement in ship performance could be shown for gas turbine drive as compared with conventional steam turbine or internal combustion engine drive. An important factor which has been largely neglected in

previous comparisons is the state of the gas turbine art and the development potential of naval (and marine) gas turbines. The basic factor accounting for the rapidity of aircraft gas turbine progress is that here the prime mover *in its simplest form* produced revolutionary changes in the performance of the engine-airframe combination. Of course, the airframe design had to be properly modified to take full advantage of the high-performance engine, but aeronautical engineers are more accommodating in this respect than naval architects. It is not in accord with traditional practice in naval architecture to design the hull of a ship around the power plant. As soon as aerodynamic compressor and turbine design combined with super-alloy development to produce a practical jet propulsion engine, it was then possible to increase flight speeds up to and through the supposed "supersonic wall." No comparable advantages could be associated with the uncooled simple cycle gas turbine engine alone for shipboard use. However, consideration of the effect on ship performance of internally-cooled (7) or ceramic-bladed gas turbines, combined steam-gas turbine plants, (8) or some other more fully developed form of gas turbine drive presents a different situation. This is not to deny the usefulness of the simple cycle unit completely for naval or marine service. That such machines may be successfully adapted to specialized naval applications such as emergency fire pump or generator drive has been demonstrated. (9) (10) In general, where economy and long service life are not primary requisites, while low specific weight and space are controlling factors, the simplest gas turbine engine is acceptable. Nevertheless, it is essential that gas turbine development be pursued farther before this prime mover can demonstrate its advantages for general naval service in competition with other machinery types.

A consideration of the difference in methods of approach employed in Britain and the United States in their respective gas turbine development programs for shipboard applications sheds some light on the general question of machinery development planning. The excellent reviews of these programs by Brown, (7) Sawyer and Simpson, (8) Sawyer, (11) and Constant (12) adequately report the major details of work done, problems encountered, and future prospects. While neither nation has achieved either rapid development or conspicuous success at this time, a practical demonstration of the feasibility of this prime mover for naval service was reached earlier under the British program. An available aircraft gas turbine was modified for boat propulsion and installed on the center shaft of a triple-screw motor gunboat (MGB 2009). Two existing outboard gasoline engines were left intact, thus affording a direct comparison of gas turbine vs. gasoline engine drive in a single test vehicle. This installation was given its first experimental trials in 1947 and was the first gas-turbine-powered craft to go to sea. The performance of MGB 2009 did not prove conclusively that naval gas turbine engines had "arrived," nor was this to be expected from such a test. It was shown that there were no serious problems of installation, operation, or maintenance involved in the application of this prime mover to the propulsion of small high-speed craft. Certain advantages of gas turbine propulsion were also demonstrated, including smoother operation and decreased noise levels. Important information was obtained from these tests on control system design, engine room ventilation requirements, and the fouling effect of operation in a sea atmosphere. At the same time, other projects were being carried out by British engineers under the method of approach employed in the United States, in which marine prac-

tice was followed from the start. There was no attempt at short-cut feasibility demonstrations, using adaptations of available units developed for other purposes, in the United States Navy program until 1947. Consequently, there was a loss of administrative enthusiasm in the period following the end of World War II in the Bureau of Ships' effort due to the absence of successful interim results. Through the use of both short-run and long-run projects, concrete results were obtained at a comparatively early stage in the British program, and interest was sustained while work went ahead on the long range investigations. Three years later, in 1950, the first marine gas turbine installation in the United States was achieved by the Boeing Airplane Company and the Bureau of Ships. (11) By this time, the British had completed a second project. The Boeing-BuShips installation was the first craft to be fitted exclusively with gas turbine propulsion machinery and was therefore a forward step. However, the advantage secured to the British by their policy of prosecuting both long and short range projects concurrently has been demonstrated. Of the six marine gas turbine propulsion installations completed as of the end of 1951, four were British projects, as shown by the following summary (11):

Project	*Type of Craft*	*G/T Shp*	*Sponsorship*	*1st Sea Trials*
MGB 2009	116′ Motor Gunboat	2500	British	Aug. 1947
TORQUIL	60′ Motor Launch	120	British	May 1950
BOEING-BUSHIPS	24′ Personnel Boat	160	U.S.	May 1950
H.L. 3964	51′ Harbor Launch	100	British	1951
BOEING-EES	36′ LCVP	160	U.S.	Aug. 1951
AURIS	460′ Tanker	1200	British	Oct. 1951

It is therefore apparent that the British policy has been more productive insofar as the attainment of objectives and the achievement of concrete results is concerned. The importance of building these features into a development program in the planning stage cannot be overemphasized. Strong emphasis is now being placed by the U.S. Navy on applications of available gas turbine engines. This trend will undoubtedly result in several operating installations in the foreseeable future. Modifications of existing non-propulsion units to permit their use in propulsion applications has been studied. It is therefore likely that small gas turbine power plants will produce an increasing supply of concrete evidence of development progress in the U.S. Navy program.

It has been stated above that further development is necessary in order to place gas turbine power plants in a generally competitive position for naval shipboard applications. Some of the major development problems are—

1. Incorporation of the necessary provisions to permit the burning of residual fuels.
2. Incorporation of turbine blade cooling.
3. Development of combined steam-gas turbine plants.
4. Development of compact regenerators.
5. Development of substitute blading materials.
6. Application of closed-cycle plants to naval service.

Most of these problems are being worked on in the current Bureau of Ships program, but the intensity of effort with

which specific problems have been attacked varies over a wide range from merely interested study to all-out investigation. While priority is now properly being given to applications of available units, the long range usefulness of gas turbine power plants depends to a great degree on the ability of industry and the Navy to find satisfactory solutions to the above problems. It is the responsibility of the Navy Department to guide and support industrial efforts to solve these problems in such a manner that gas turbine power plants incorporating a maximum amount of used potential are developed with a minimum expenditure of time, effort, and funds.

There is no general agreement on the order of importance of these problems, but there is considerable evidence that the ability to burn residual fuels should have first priority. Current efforts to incorporate this feature into diesel engines lends authority to its importance. In spite of a marked superiority in fuel economy among existing prime movers, the diesel engine has been limited in the scope of its application in naval and marine service by the restrictions on fuel required for its satisfactory operation. Current reports of the successful operation of these engines on residual fuel indicate strong resistance to displacement by gas turbines in their overlapping areas of application (e.g., small boat drive). While the United States Navy has not placed major emphasis on the residual fuels problem in its gas turbine development program, the British have given this question first priority in both governmental and commercial efforts. Dr. Brown (7) states "In the development of the gas turbine for marine propulsion, the main research required is to establish the ability to burn heavy fuel without fouling or corroding the turbine blading or heat-exchanger surfaces. As long as efficiencies of the order of 30 percent are all that can be obtained, and the production cost of gas-turbine units is high, it is essential that gas-turbine units should be capable of burning boiler oil of the same quality as that used in furnaces of boilers in steam-turbine-driven vessels." The scope of application of gas turbines now available to naval service would be increased in advance of other expected future improvements. Accelerated development would follow increased service use, with a consequent rapid increase in "used potential."

Combustion of residual fuels is not the bottleneck in their application to gas turbines. (13) Avoidance of the deposition of ash and of the secondary effects (corrosion and erosion) in the turbines and heat exchangers caused by the ash are the major problems. Combustion chamber liners may be replaced at reasonable periods without difficulty, but turbine blades and heat exchanger surfaces present a different problem. An understanding of the mechanism of deposition and corrosion resulting from the use of residual fuels is being gained, but the necessary corrective methods have not yet been determined. Some possible remedies include coating of metallic surfaces subject to attack, periodic removal of deposits by cleaning, and treatment of fuels to reduce deposition tendency. These measures are mitigating methods rather than eliminating methods, and are therefore not final answers.

Turbine blade cooling is a necessary development for two principal reasons. First, the employment of the high turbine inlet temperatures (1800-2500°F.) at which the thermal efficiency of a gas turbine engine is equal to or better than that of the best existing machinery is not in sight with any present or prospective metallic alloy. Second, competition for the critical materials required for high temperature alloys between the aircraft industry and other gas turbine users requires consideration of all possible methods for reducing the need for these materials. One well-informed au-

thor (12) has stated "It is now beginning to be appreciated, however, that the non-existence of materials capable of operating satisfactorily at high temperatures need never have prevented the development of the gas turbine. For recent ideas on the cooling of metal surfaces by fluids have shown that it is possible to operate a gas turbine at sufficiently high gas temperatures to obtain a reasonable performance without the use of special heat-resisting materials. Before the development could start, therefore, it was necessary to have either high-temperature materials or the techniques of cooling." Incorporation of blade cooling, therefore, may be used to permit either (a) the employment of maximum gas temperatures by internally-cooled superalloy blades or (b) the reduction of critical materials requirements by internally-cooled blades of ordinary steel at the gas temperatures now used. Indeed there is no technical reason why both objectives should not be pursued simultaneously, but practical limitations of funds, facilities, time, and personnel make such a dual purpose program objectionable. However, it is likely that a satisfactory blade cooling method will be used for both purposes when it is made available.

A steam cruising-gas booster plant offering a 28% reduction in propulsion plant weight on a total rating of 30,000 shaft horsepower was proposed by Mr. S. A. Kane, then of the Bureau of Ships, in 1946. (8) This weight reduction is obtained by employing a steam turbine plant of 9,000 shp in combination with a gas turbine plant of 21,000 shp. Studies of service operation in wartime have shown that, even though higher cruising speeds were employed than in peacetime operation, a major part of the plant capacity is carried around on a virtual "standby" basis on major combatant vessels even under wartime conditions. Since 20% of the installed propulsive power accounts for over 90% of the underway time, an appreciable reduction in weight of the upper 80% of installed propulsive power should be welcome. The proposed plant was intended to utilize available machinery components with the exception of the arrangement of the main reduction gear. Traditional naval machinery maintenance concepts would be compromised initially to the extent of permitting replacement of the interchangeable "package" gas turbine elements on aircraft overhaul standards (about 1,000 hours). This is not too great a sacrifice for the objective, and should be capable of 50-100% increase within a year by careful service evaluation and modification. This maintenance practice is not a great departure from that employed on landing craft and small boat engines in World War II. The increased complexity of naval vessels has sharpened the competition for each available cubic foot of space on shipboard while displacements and power requirements have gained consistently. This condition is found in virtually all types of combatant ships and some others. Reduction in power plant specific weight and volume is therefore necessary in order to accommodate increased complements of ordnance, electronic, and other gear essential to the tactical readiness of naval vessels without compromising the maneuvering characteristics. The development of combined cycle plants such as that proposed by Mr. Kane offers advancement along much-needed lines.

The remaining problems in naval gas turbine development are less critical than the first three discussed above. Compact regenerators are needed to offset the high fuel rates of currently available units, but the advent of successful turbine cooling schemes would diminish the need for regenerators in view of the increased economy due to cooling alone. The time required to develop compact regenerators of high (70-90%) effectiveness is apparently of the same order of magnitude as that required for turbine cooling develop-

ment, while the increased weight and space required by regenerators now available often nullify the major advantages claimed for gas turbine plants. Substitute blading materials for the metallic alloys now used have shown great theoretical promise but the practical results have been disappointing. Ceramics and ceramic-metal combinations have long been known to have superior heat-resisting properties at high temperatures in comparison with metallic materials, as well as lower densities. Low resistance to thermal shock has not yet been overcome, therefore the substitute materials are still in the experimental stage, particularly with respect to their use in rotating parts. Ceramic coatings have reached the application stage in stationary parts (e.g., combustion liners). Ceramics and ceramic-metal combinations are of interest to gas turbine engineers primarily as an alternative to turbine blade cooling, therefore a satisfactory solution to the latter problem would diminish the need for substitute blading materials. Closed-cycle gas turbine plants, employing air unmixed with combustion products as a cycle fluid, are of interest as prospective naval shipboard power plants for two principal reasons. First, the size of required ductwork and of the main components is decreased for large power ratings in closed cycle plants as compared with open cycle plants (with one exception). Second, the closed cycle plant offers an alternative means for the use of nuclear energy in shipboard power generation. There has been little active interest in these plants in the United States but an advanced stage has been reached in Switzerland where the closed cycle originated. A 2000 KW test plant erected in 1939 is still in operation furnishing electric power to supplement a hydroelectric grid. The exception noted above to the weight and space advantage of closed cycle over open cycle units is the air heater, which has offered strong resistance to attempted reduction of its size to reasonable proportions. In a 12,500 KW generator plant, the air heater accounted for 30% of the total weight and cost. The excessive weight and space requirements of this element are a major factor in the absence of closed cycle plants from the Bureau of Ships program.

It is apparent from the foregoing discussion that an area of considerable extent in which there are challenging problems still lies ahead in the full development of naval gas turbines. What is the justification for getting involved in these problems beyond the salvaging of funds already spent? The major advantages to be expected from the application of these prime movers to naval use are:

1. Reduced power plant weight and space.
2. Increased fuel economy and cruising radius.
3. Greater safety in action.
4. Reduced danger of smoke emission.
5. Greater availability.
6. Elimination of feed water.
7. Reduced operating personnel requirements.
8. Reduced maintenance requirements.
9. Greater adaptability and scope for continued improvement.

The naval gas turbine installations which have been completed up to this time have not demonstrated these advantages in a sufficiently conclusive manner to establish this prime mover firmly in the hierarchy of naval shipboard power plants. An effective development program directed toward the solution of the problems discussed above, together with the continued application of available gas turbines to special jobs, will result in a major contribution to naval engineering.

NUCLEAR POWER PLANT DEVELOPMENT

Some of the most difficult technical problems in naval shipboard power plant development today arise in the employment of nuclear energy for the propulsion of naval vessels. No discussion of current power plant development in any field of application would be complete without some reference to nuclear energy. At the same time, it must be admitted from the start that security considerations restrict the scope and the degree of detail of available unclassified information so greatly that such discussions are likely to be unsatisfactory. Within these limitations, an attempt will be made to compare development problems and progress in this program with that on gas turbine power plants. Information concerning the power generating aspects of nuclear energy has never been freely available due to the difficulties encountered in declassifying information on reactors for power application without violating the secrecy of other applications. Consequently the available information has been chewed over again and again in an effort to understand the subject. (14) (15) Increased effort has been directed toward the declassification and release of useful information by the Atomic Energy Commission (AEC) where security considerations permit. Data on low-power reactors has been made available in this manner and continuing studies are underway to explore the possibilities of nuclear power for industrial purposes. (16) While the Navy Department has not suffered directly from these security restrictions, the general progress in nuclear science and engineering has been retarded, particularly with respect to industrial power generation. In spite of these difficulties, progress has been made toward the realization of nuclear powered naval vessels through the cooperative efforts of the Navy Department and the AEC.

Gas turbine engines were developed first for military purposes. Commercial applications are increasing but will probably not reach large numbers until further development now in progress has been completed. Nuclear power plants are likewise being developed first for military use. The high cost of power plant development requires that the Government supply the necessary support where industry cannot justify the required expense. Small reactors cost from 1 million to 5 million dollars, while larger units cost from 25 million to 50 million dollars. The cost of the first shore prototype reactor for submarine propulsion is estimated at $1400 per KW installed capacity compared with $110-$140 for conventional steam power plants. (14) It was therefore a logical conclusion, even without security restrictions, that the first power reactors would be developed by government funds for military use. The Navy was in a favored position from a technical viewpoint as the user of the world's largest mobile power plants and possessor of the world's biggest fuel logistics problems as a result. It should also be noted that the nuclear reactor-steam turbine power plant *in its simplest form* offers great performance improvements in naval vessel propulsion for which large expenditures can be justified. With respect to gas turbines, it was shown that no such case could be made for "writing a blank check," consequently the support of and emphasis on nuclear power development has been several times that on gas turbine development. Since 1948, the Navy nuclear program has had strong support from the AEC. (17) Since this agency has a strong provision for sponsoring research and development on all phases of nuclear energy in its enabling act, its cooperation is essential to the success of the Navy's efforts. Of course it is expected that the development of naval nuclear power

plants will be a step toward industrial nuclear power plants. Economic considerations will determine the utilization of nuclear power by industry, and the major part of the cost of generating and distributing electric power will not be affected by these developments. However, nuclear power plants will be useful in supplementing conventional power plants in the continued expansion of power generating facilities. (18)

The first military application of gas turbine power was to aircraft propulsion. Nuclear power plants for this purpose are under development, but have not reached a comparable stage with the shipboard application so far as unclassified information has shown. Dr. Kingdon (15) has indicated two reasons for this lag. While the primary interest in nuclear propulsion for both ships and aircraft lies in the tremendous increase in cruising endurance per unit weight of fuel carried, there are fundamental problems in the latter application not present in the former. First, the requirement for a biological shield to contain the dangerous nuclear radiations within the power plant of an inhabited vehicle makes the requirement of light weight particularly difficult to satisfy, especially in view of the restrictions on permissible materials. Second, the ability of nuclear fuels to liberate energy without a combustion air supply is not advantageous for jet propulsion. On the other hand, all the reactor development problems discussed below are common to both applications. The conclusion may therefore be drawn that the order of application of nuclear power to aircraft vs. ship propulsion will be the reverse of that followed with respect to gas turbine power.

It is now well known that the nuclear power plants currently under development for naval shipboard applications employ nuclear reactors in combination with steam turbines. The primary development problems of these power plants are concerned with the reactor. The central objective is to permit the use of nuclear fuels in place of the conventional fuels in order to take advantage of the increased energy liberation per pound of fuel associated with nuclear reactions. Some of the obstacles (14) in the way of attaining this objective are the development of

1. Materials to stand higher temperatures than are attainable from chemical reactions.

2. Materials which show minimum radiation damage under the intense bombardment of neutrons, gamma rays, etc., inside the reactor.

3. Materials which do not absorb and waste an excessive proportion of the available neutrons.

4. Shielding of personnel and instruments against the adverse effect of radiations.

5. Control gear with response times adequate for safety.

6. Means for handling heat transfer rates considerably higher than those conventionally used.

7. Means for controlling the radioactive materials produced in the fission process and deposited with the fuel elements to the detriment of the neutron economy.

8. Means for handling and ultimate disposal of radioactive wastes in a manner which will constitute the minimum health hazard.

These problems are all being worked on in the current AEC-Navy Program and the success of the application projects, including those for submarine propulsion, depends upon their satisfactory solution. Applied research in AEC laboratories has provided reactor engineers with adequate "handbook" design data, but the adequacy of the current designs has not yet been established by full-scale tests. (14) The keel of the U.S.S. *Nautilus,* the world's first nuclear powered submarine, has been laid.

A contract has been issued for the construction of a second nuclear powered submarine. Test results on these two projects will supply the necessary preliminary evaluation of the current reactor designs for power purposes (in contrast to the early reactors designed primarily for the production of fissionable materials). Land-based prototypes of the power plants for these experimental ships are now being built. The *Nautilus* power plant employs thermal (low energy) neutrons while the second plant is of advanced design employing neutrons of intermediate energy.

The nature of the reactor problems listed above obviously requires a development program which bears a greater research burden than is required for gas turbine development. A description has been given of the rise of the "nuclear engineer" in response to these new demands. Nuclear engineering includes much that would be classified as applied research in the usual sense. The design of a new reactor always calls for facts which have not yet been obtained. An appreciable part of the applied research from which the necessary design data is obtained is performed by nuclear engineers. It has not been necessary for the Navy Department to establish its own facilities in a complete sense for nuclear power development due to the support of the AEC. Applied research for reactor development is an important part of the AEC program, (19) and it is from this source that the answers to the problems listed above are expected to come.

"Although there is necessarily much overlapping, research for reactors may be grouped into three broad fields—nuclear physics, metallurgy, and chemistry. This is the work the scientists do. Engineers also have three fields—chemical, mechanical, and heat transfer engineering. The work of all the investigators is almost exclusively programmatic, for it is aimed at the one objective of building reactors. The experimenters seek more basic knowledge in the still relatively unexplored field of nuclear physics; they determine the properties of rare elements that hold promise in reactor design; they open up a new branch of chemistry and chemical engineering in separating valuable materials from the mixed output of reactors. Engineers devise control systems that meet the new requirements of reactor operation, and heat transfer specialists work in a new realm of more rapid rates of transfer at higher temperatures." (19) Thus the AEC officially recognizes the dependence of reactor development on applied research. In order to supply essential information required by reactor designers and builders on materials, a materials testing reactor is now in operation at an AEC facility. This test unit operates primarily on thermal neutrons but can also subject specimens to neutrons of intermediate and fast energies. The effects of intense radiation on materials for use in reactor structures, shields, and coolant systems can be determined in advance of actual construction by exposing test specimens in this unit. More than 100 ports are provided for this purpose. It is not unreasonable, therefore, to assume that the materials and shielding problems of reactor development will yield to solutions indicated by the materials testing reactor.

Some of the reactor development problems listed above lie closer to the traditional engineering pursuits than others. Even these, however, cannot be considered conventional mechanical or chemical engineering tasks. Mechanical and chemical engineers are accustomed to dealing with problems of instrumentation and control, heat transfer, waste disposal and decontamination, and safety measures for the protection of personnel. However, conventional power plant and chemical process plant technology does not involve radio-activity and the preservation of neutron econ-

omy. The effects of these important additional considerations will be apparent from the following example. (15) A good reactor coolant should be light in density, low in neutron absorption capacity, suitable for circulation at high temperatures in a piping system, and economical in cost. These attributes are required in addition to good heat transfer properties. Various reactors have employed air, water, and liquid metals. Air is a relatively poor reactor coolant due to its low density and low thermal conductivity. The large heat transfer surface area required is particularly objectionable for mobile power plants. Water is superior to air, but new restrictions on the reactor are introduced. The hydrogen in water slows down the neutrons so rapidly to thermal energies that any water-cooled reactor must necessarily operate with thermal neutrons. Also, the operation of a water-cooled reactor at the elevated temperatures required for economy in power production introduces the necessity for dealing with high pressures within the reactor structure. Liquid metals have the best thermal properties for use as reactor coolants and also have relatively small pumping power requirements, but these substances have other disadvantages. Sodium, which has good thermal and pressure characteristics, reacts violently with water. In the selection of a coolant, therefore, several problems must be solved simultaneously.

These reactor development problems are comparable to the aerodynamic compressor and turbine design problems and materials inadequacies which delayed the arrival of gas turbine power plants. Without adequate compressor and turbine efficiencies and either superalloys or turbine cooling systems, there would be no useful gas turbine engines. Without adequate materials, shielding methods, control gear, and the other essentials for extracting heat safely from nuclear reactors at economical temperatures for power production while preserving the neutron economy, there will be no useful nuclear power plants.

V. Adm. C. A. Lockwood has indicated the scope of the advantages to be gained by the application of nuclear power to submarine propulsion, saying "The conception of the atomic submarine is the greatest stride ever made in naval science." (17) R. T. Sawyer (20) has discussed the promise of nuclear propulsion for aircraft carriers. In general, the following advantages are anticipated for nuclear-powered naval vessels—

1. Greatly increased cruising radius.
2. Reduced fuel logistics problems.
3. Reduced maintenance material requirements.
4. Reduced personnel requirements for operation and maintenance.
5. Increased scope for continued improvement.
6. Elimination of smoke.

While these items appear to be similar in many respects to those listed for ships powered by fully-developed gas turbine engines, the differences are of magnitude rather than kind. With respect to improvements in cruising radius, for example, gas-turbine-powered ships are subject to the same logistic limitations of fuel supply which control operations with ships having conventional power plants. Since all these drives employ chemical fuels, increased cruising radius can only be obtained by increased plant economy or increased fuel capacity. Sustained high speed cruising is practically impossible under these conditions. Nuclear fuels are relatively independent of logistic limitations, therefore nuclear-powered ships will not only have increased cruising radii at normal cruising speeds but will be capable of sustained high-speed cruising. The resulting tactical advantages are obvious.

Successful completion of the naval nuclear power plants now under development will go a long way toward the establishment of this propulsion system in naval service. While the first naval gas turbine power plants were not designed for shipboard installation, both submarine nuclear power plants have been designed to Navy standards as shipboard installations. The land prototypes are being built to designs which have been thoroughly reviewed for the inclusion of the various considerations previously outlined in the section on naval shipboard power plant requirements. Since the naval nuclear power development program was not initiated until after the end of World War II, the progress of the submarine propulsion projects has shown a rapidity not characteristic of naval shipboard power plant development in general. This is evidence that the evolution and application of new naval power plants need not take as long as it usually does.

SERVICE EVALUATION IN RELATION TO DEVELOPMENT

A preliminary evaluation of a new or improved design of naval machinery is afforded by shore tests and acceptance sea trials, but the ultimate test on which any such development must stand or fall is the record of its performance and reliability under service conditions. An examination of the requirements given above for naval power plants illustrates clearly that several of the most important factors can only be evaluated with any degree of certainty by actual service operation. Full-scale trials may be of considerable value if sufficient data is taken and the results are carefully analyzed, but it is impossible to reproduce all or even a majority of the conditions encountered in service. Extreme care must be exercised in the interpolation and extrapolation of such test results to predict what will happen under other conditions.

The most satisfactory method of evaluation is by a system of continuous monitoring of actual service operation, such as that now used by the Bureau of Ships. An effective monitoring system must include the following elements—

a. An adequate reporting system.

b. Adequate administrative authority.

c. Competent analysis and interpretation.

d. A follow-up system.

Since the whole evaluation rests on the basis of the reports submitted by service operating personnel, the importance of the reporting system is evident. Report forms must be carefully designed to obtain all essential data without undue time demands on operating personnel. Recent changes in the forms used by forces afloat to report machinery performance to the Bureau of Ships have increased the value of the data reported while reducing the time and labor involved. The cooperation of operating personnel afloat is also necessary, therefore the reporting system must be supported by adequate administrative authority. When an acceptable reporting system has been established, it is necessary to have a competent staff on the receiving end to translate the raw report data into intelligible and useful form for the persons who are expected to take action. Just before World War II, Mr. H. F. Smith originated the concept of employing engineering and statistical analysis in combination to evaluate machinery performance and reliability under service conditions. Information made available in this manner may be utilized for design, operating, maintenance, or logistics purposes. An adequate follow-up system is required in order to determine (a) that the prescribed reporting system is followed, (b) that corrective action or

improvements indicated by the analysis are put into effect, and (c) what effects have resulted from the action taken. The monitoring system is, in effect, a "feed-back" system which supplies a continuous flow of data on machinery performance and reliability under service conditions for the benefit of the Bureau of Ships and other activities of the Navy Department.

Important contributions to shipboard power plant development can be made by an intelligent analysis and application of the results of service experience. Analysis of service performance isolates the primary variables affecting a given characteristic (e.g., fuel rate) both qualitatively and quantitatively, and points out directions in which development may be expected to produce improvement in that characteristic. Analysis of material reliability indicates items on which the development cycle is incomplete in the sense described earlier. It has been shown by such analysis that the propulsion plant use factor for many of the major combatant ships is unfavorable to traditional propulsion machinery design concepts. In the preceding discussion of gas turbine engines, the possibility of reducing main engine weight and space requirements per shaft by the use of lighter machinery for the upper 80% power range was shown. A mental barrier to the acceptance of this concept lies in the traditional practice of designing the entire propulsion plant for the same long-life requirement. In the absence of reliable plant usage data, the traditional design practice is defensible. Now that service performance analysis has provided a factual basis for a new design approach, development can proceed along the indicated path. These analytical procedures are therefore useful not only in indicating profitable lines of development for available machinery but also for indicating areas where new machinery systems or components are needed.

CONCLUSION

How effectively is the Navy Department discharging its responsibilities with respect to naval shipboard power plant development? The practical answer to this question depends upon whether the Navy Department can buy (or build) the best power plants for its various shipboard applications when the need arises. Today's procurement situation depends upon yesterday's research and development program. The power plants available this year are dependent upon the effectiveness of research and development in preceding years. Steam turbine and reduction gear improvements in World War II destroyers were the result of development work initiated in 1936, and other instances may be cited. A development program is *adequate* when it produces results in the form of development products which satisfy specified requirements. An *effective* development program must not only be adequate but must also obtain the desired objectives within reasonable estimates of time, cost, and effort. Naval ships have grown larger and more complex in order to accommodate modern ordnance, communications, and other equipment. At the same time, research and development costs have increased. This rising spiral of more research and development at higher costs requires increased emphasis on effective planning and execution of research and development programs.

When the Navy Department steps out ahead of industry and initiates the development of new types of power plants for which there is no existing commercial demand and no record of experience, it is fulfilling its role most effectively. At the same time, the normal difficulties associated with development

work are greatly multiplied. Lack of commercial demand may impose the full cost of development on the Navy Department, therefore strong financial support is essential. The time required to produce a satisfactory prototype engine is increased due to the number of unknown factors involved. Commitments must be made on the basis of engineering judgment with inadequate information at hand. Applied research may be required on a large scale, resulting in additional delay in reaching final results as well as increased cost. These and other problems have been encountered in the programs discussed above. The strongly-supported, centrally-administered nuclear power effort has shown remarkable progress in the face of technical problems probably the most difficult and complex in the recent history of power plant development. While the technical problems of gas turbine development are less difficult, the support given this effort has been less enthusiastic and its administration more diffused. Progress on the respective programs has reflected the degree of effectiveness of Navy Department administration.

In the Semiannual Report of the Secretary of the Navy for the period 1 January thru 30 June 1951, it is stated that "The ability of the Active Fleet to accomplish its missions depends, to a large degree, on the Navy's continuing programs of research and development. This is understandable—from those programs come new weapons, ships, aircraft, equipment, and operating techniques which keep the Navy's material readiness progressively ahead of potential enemies." The programs discussed in the foregoing sections are aimed at keeping the Navy's shipboard power plant readiness progressively ahead of potential enemies. While there have been the usual extravagant forecasts that the new power plants will inevitably supersede those now in use for all applications, past experience indicates otherwise. A general purpose power plant capable of meeting the propulsion and power generation requirements of all naval ship types is an extremely attractive objective. However, the varied requirements of aircraft carriers, PT boats, landing ships, cruisers, minesweepers, submarines, and other naval craft are not likely to be met by a single type of engine. Both gas turbine and nuclear power plants will find proper places in naval shipboard service, but not to the exclusion of conventional types. The reciprocating steam engine is still in use in many marine and some naval applications even though it was pronounced dead many years ago.

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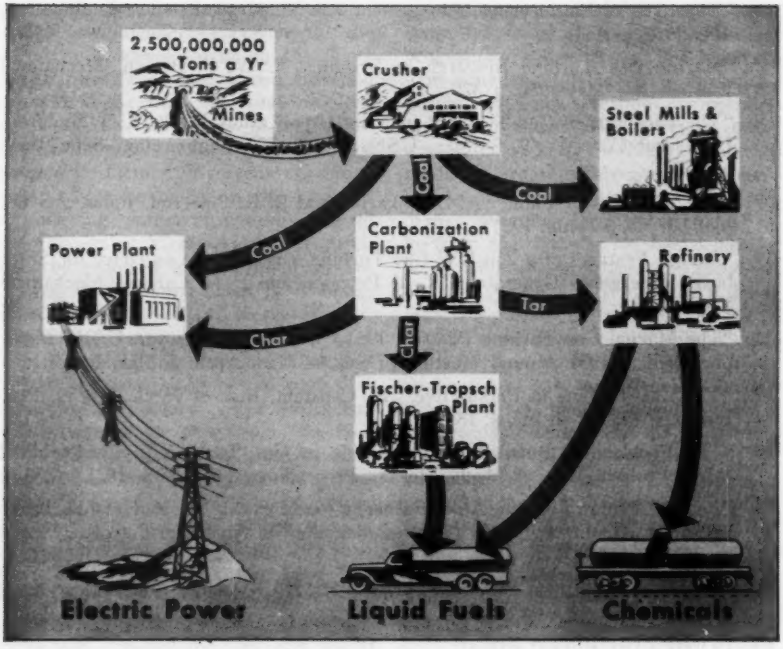

How the Coal Industry Will Look 50 Years From Now

It seems that a plausible picture of the coal industry by the end of this century is as follows:

1. Coal will be mined at low cost with ingenious machines in terrific volume.

2. The coal then will be crushed.

3. The fine coal will be processed continuously in some sort of so-called low-temperature carbonization equipment, with or without an atmosphere of hydrogen.

4. The tar from the operation will be worked up to liquid fuels and a minor quantity of needed chemicals. The liquid fuels will be transported by pipe line to suitable points for retail distribution.

5. The char from the operation will be transported by pipe line to suitable points for the generation of electric power.

6. If the production of char is greater than the electric-power industry needs, a portion of it can be converted to liquid fuel by modification of Fischer-Tropsch process.

7. The quantity of coal handled in this way is likely to be at least five times present production.

This is not necessarily what *will* happen—but it *could* happen. The important thing for all of us to keep in mind is that what actually will happen is not to be determined by our desires or our hopes or our hard work.

The future will be determined by the needs of energy consumers, by the course of technologic developments and by the circumstances of our fuel reserves. And it will represent the welding of three great technologies—coal, petroleum and electric power.

We shall all move more rapidly if we swim with the economic and technological tide.

COAL-FUEL OF THE FUTURE

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This article originally published in the April 1952 issue of "Coal Age," was written by MR. EUGENE AYRES, Technical Assistant to the Executive Vice-President, Gulf Research and Development Company.

The fuel industries are the base for the way of life to which we have become accustomed.

The greatest of these industries are coal and petroleum. They are alike in the fundamental respect that they provide fuel for comfort and for generating power for our industrial economy. But they differ in important respects and they are intricately intertwined.

We all are familiar with the fact that our coal reserves are immensely greater than our petroleum reserves. Although estimation of recoverable reserves is little more than educated guesswork, it is significant to observe that the maximum estimate of reserves of oil plus natural gas is only 10% of the *minimum* estimate for world reserves of coal. For the United States, the figure is 18%.

If we reverse the process and compare minimum estimates for oil plus gas with *maximum* estimates for coal, we arrive at less than 1% for either the world or the United States. The true picture, as it will develop in the future, probably will lie somewhere between the two extremes. In the United States, recoverable oil plus gas is likely to run about 3% of recoverable coal.

We have other fuels, of course. There is oil shale, for instance, which eventually may provide about 3% as much energy as coal. And we have some tar, which will provide scarcely a trace of energy, and peat, which someday may give about 1% of coal. But the conclusion is inescapable—and always has been inescapable—that our future economy over the next two centuries is at the mercy of a sound coal industry.

HOW COAL AND OIL DIFFER

We are inclined to talk about the petroleum industry and the coal industry as though the word "industry" meant the same thing to each. It does not. And here's why:

A fuel industry may be made up of one or all of four different departments, as follows:

1. The mining of coal or petroleum —the recovery from the earth of crude or run-of-mine material.

Here the differences are sharp and clear. The removal from the earth of liquid or gas is a much simpler physical operation than the removal of solids. But for oil, we have the added task

of discovery, which for coal is largely a matter of ancient records. The discovery of oil has been a profitable gamble, but a gamble none the less, and one which someday will become unprofitable.

2. The conversion of the crude to marketable products.

Here again the difference is marked. At present, considerable run-of-mine coal is sold for use without beneficiation. Almost no crude petroleum is used as such. The conversion of crude oil is essential to obtain the kind of liquid fuels required by the motor-car and other major petroleum markets. The refining of petroleum has its counterpart in the conversion of coal to electric power. People can do things with electric power that they cannot do with coal. Likewise, they can do things with motor fuel that they cannot do with crude petroleum.

But when a coal company manufactures power for sale, it is no longer regarded as a part of the coal industry. Instead, it suddenly becomes a part of the public-utility industry. Yet the operation is not fundamentally different from the conversion of oil to motor fuel for public retail sale. Later on, of course, another major conversion for coal will be to motor fuel.

TABLE I—HOW PETROLEUM IS MOVED IN THE UNITED STATES

	Per Cent
In industry-owned equipment:	
Pipelines	36
Tank trucks	28
Marine tankers	16
Marine barges	10
In railroad-owned tank cars	10
Total	100

From *Energy Sources: The Wealth of the World*, by Ayres and Scarlott.

TABLE II—HOW HOME-HEATING SYSTEMS RATE EFFICIENCY-WISE

Energy System	Efficiency Including Necessary Conversions
Electric with heat pump:	
Performance coefficient, 4	65
Performance coefficient, 3	49
Oil	61
Natural gas	61
Coal, domestic stoker	60
Enriched water gas	46
Coal, hand-fired	42
Electric (national average)	16.3

3. The transportation of fuel to its points of use.

Here we note an important difference. Nearly 90% of petroleum is transported in equipment owned and operated by the petroleum industry, as shown in Table I. This equipment includes, pipe lines, marine tankers, marine barges and tank trucks. Only about 10% of petroleum is carried on railways. The control of transportation is essential to the petroleum industry and eventually will become essential to an integrated coal industry.

In contrast with oil, the great bulk of coal ton-miles involves equipment owned and operated by others, principally railways and ships. When a coal company moves its own coal for long distances, it is likely to be exiled into the railway industry.

Pipe-line transportation of coal appears to be in the offing. It will come, but it has been a long time on the way, the first experiments in pipe-line transportation of solids having been made in 1860.

4. The distribution of energy to ultimate consumers.

A lot of coal is distributed by the coal industry but about 22% is distributed in the form of electric power and gas by public utilities. Nearly all

petroleum is distributed by the petroleum industry. A very little—less than 4%—is sold by public utilities in the form of electric power and manufactured gas.

In addition to their differences in these four departments, the oil and coal industries differ in the scope and integration of their operations. To be sure, all kinds of oil companies form the oil industry. A few are concerned only with recovery of fuel from the earth. A few purchase crude oil, which they refine and market. Some have no facilities for transportation and distribution. But the major oil companies are fully integrated and function in all four ways—recovery, conversion, transportation and distribution.

On the contrary, coal companies rarely are integrated except by losing their primary status as coal companies. Some of them are so-called "captive" companies absorbed by public utilities, the steel industry or railroad. The coal industry still is largely a mining industry. Mining has not yet become incidental to manufacture, transportation of energy and distribution of final energy forms to ultimate consumers.

NEW ENERGY FORMS WANTED

Trends of fuel consumption over the past few decades have been confusing. We have been going through—and still are going through—a transition period from which certain unmistakable trends are beginning to emerge. Our economy is strongly characterized by two developments:

1. Increasing preference for electric power, which means coal, and . . .

2. Increasing preference for liquid and gaseous fuels for end uses, which means petroleum now and coal later on.

The accelerated demand for electric power is almost sensational. Some recent studies show that the rate of demand for electric power is going up at least 1.6 times as fast as the rise in gross national product. The reasons for this phenomenon are so many and so varied that we cannot go into them here. But in spite of optimistic programs for building generating stations a power shortage now is with us and is likely to continue for some years. To double an industry every 10 years is no mean task. Electric power demand now is going up even faster than that.

Our hydroelectric installations sometimes are described as vast, but terms like this are relative. The total energy now derived from water power is only about equivalent to the fuelwood we burn or to the quantity of anthracite produced—about 4% of our total energy requirements. New waterpower installations will be made, but the maximum practical increase will take care of only a minor part of expansion within the next few decades. So we find that the most rapidly increasing demand for energy is in the domain of coal.

WHERE OIL SHALE FITS IN

During recent months careful studies have been made of costs of recovery of liquid fuel from oil shale and coal. On the basis of present technology it is much cheaper to make motor fuel from oil shale than from coal. For this reason, oil shale will be exploited first, but this development cannot be expected to postpone more than a few years the large-scale conversion of coal. These are the reasons why coal will move into the picture:

1. Low-cost oil shale is limited to thick deposits with horizontal cleavage from overburden, located on the sides of deep canyons for disposal of ash from retorts. Oil shale yields only about 10% oil—the rest is ash. On the average, it will be necessary to dispose of more than a ton of ash for every barrel of oil.

2. All low-cost oil shale is located in Colorado and Wyoming, where water is scarce.

3. The rate of increase in demand for liquid fuel can be taken care of by supplemental oil-shale operations for only a few years.

4. Since technologists know that our ultimate dependence must be on coal, extraordinary efforts will be made to lower the cost of coal conversion.

HOW COAL WILL BE USED

So the picture for the long term is that the downward trend of coal's proportionate share of our energy demand will be sharply reversed. While the demand for liquid fuel probably will continue upward for a long time, more and more of the liquid will come from coal. In the meantime, coal will be required to an increasing extent for electric power. On the other hand, the use of coal as such will go downward for nearly all applications except conversion to electric power, to metallurgical coke or to liquid, and for generation of steam in large boilers. In this respect, coal may become like crude petroleum, less than 2% of which is used as such.

There are many good reasons for expecting this sort of industrial demand. Competition between industries is a curious thing. We often try to accomplish an illogical task when that happens to be our business. But it always is a losing battle. For example, in Washington, D. C., where strong competition exists between the oil and natural-gas industries, both industries want the home-heating business. But gas will win out in the end, if it is in sufficient supply and if prices of the two are comparable, because gas is nicer to use.

In some other cities, gas and electric power are competing for kitchen ranges. Given costs not too far apart, electric power will win out because it is nicer to use. In 1950 the ratio of gas ranges to electric ranges sold narrowed to about 3:2, against a ratio of 16:1 in 1935. The ratio of gas to electric ranges in service has declined from 20:1 in 1935 to 4:1 in 1950. Thus, in transmuted form, coal is moving back into the kitchen.

Electric power has not yet come into its own for home heating but the handwriting is on the wall. Thousands of new homes with electric heating now are under construction. With heat-pump installations, electric power already is beginning to displace gas, as gas is displacing oil and oil is displacing coal. The reason is clear. Electric power is nicer to use. Coal is in the way of completing a full cycle.

NEW LIGHT ON DIESELS

The displacement of the steam locomotive by the diesel-electric now is a familiar story. But the story is not yet fully told. When oil finally is obtained from coal, the diesel-electric may be displaced by some efficient coal-burning device, since the over-all efficiency of coal conversion plus diesel-electric conversion would be much lower than that of a gas turbine, for instance.

Diesel-electric developments have made conflicting impacts on coal economy. In 1948 transportation of coal was about 200,000,000,000 ton-miles. The coal required for this transportation would have been about 36,000,000 tons if the whole job had been done by coal-burning steam locomotives. But the coal equivalent of the oil required, if the job had been done altogether by diesel-electric locomotives would have been about 13,500,000 tons—little more than one-third as much.

Thus the market for coal is contracted by the substitution of oil. Yet since it costs less to move coal by diesel-electric locomotive, the expansion of the coal market in other directions *should be* far greater than the contraction attributable to diesel inroads. Nearly half the cost of coal on the Atlantic Coast is for transportation. It happens that freight rates are going up, but it may be presumed that the rise would have been more rapid if the diesel had not moved in. Here, then, is an instance where the sale of oil may accelerate the sale of coal.

Another somewhat similar story is the development of steam-turbine oils that last 20 times as long in service as former oils. These oils have contributed to the low cost of electric power, which means more sales of electric power and a bigger utility market for coal.

Gasoline or diesel fuel in an amount equivalent to 500,000 tons of coal per year is required to deliver about 100,000,000 tons of coal by motor truck to points of ultimate retail use. A cheaper or more convenient way to deliver coal would be difficult to find. It happens that approximately the same amount of coal—500,000 tons—is required to generate the electric power used for the production of oil and gas.

ENERGY LOSS—COAL AND OIL

Energy always is required to convert fuels from one form to another. The thermal efficiency of modern oil refineries average about 87%. In other words, 13% of the crude, or an equivalent amount of energy from other sources, is required to operate the refinery. Some refineries therefore burn coal to conserve oil. This practice is likely to grow. On the coal side, losses somewhat greater than 13% occur in making a finished product from run-of-mine coal.

The thermal efficiency of conversion of coal to electric power now averages about 21%. Large modern plants, of course, do much better. Though this figure seems low, electric power is utilized with high efficiency for heating as well as for power.

Meanwhile, with efficiencies of power plants going up and destined to rise still further, the thermal efficiencies of oil refineries have been going down—and must continue to go down—because of the growing complexity of liquid-fuel preparation. When the time comes for conversion of coal to motor fuel, efficiencies are likely to run about 75% instead of the present 87%. This figure seems high compared with the best electric-power generation. But if we balance the conversion inefficiency and the utilization efficiency of the coal-electric power system against the conversion efficiency and utilization inefficiency of the liquid-fuel system, we see that the two energy systems are pretty much on a par.

EFFICIENCY—BIG MARKET FACTOR

The excellent work of electric-power engineers in improving efficiencies of power-generating plants means, of course, less coal per kilowatt-hour, but it also means more coal per annum or per capita because people use more electric power when it is cheap. A somewhat similar paradox is found in the development of more efficient sources of light. The Welsbach mantle, for example, tripled the light output of gas burners but instead of cutting consumption of fuel to one-third, the invention increased the demand for fuel manyfold by providing more adequate light. This has happened with every subsequent improvement in light generation.

Likewise, the reason that demand for motor fuel has gone up so steadily and so rapidly is that the oil industry has found ways of keeping the cost of motor fuel (*ex taxes*) from rising for the past 25 years. This achievement has been notable because the quality of motor fuel has been radically improved over the period.

One reason for the usefulness of oil and gas is that they can be transported easily in pipe lines for thousands of miles. Electric power is limited in this respect. Engineers see little prospect of increasing the distance for transmission of electric power beyond the present 300 to 500 miles. For large blocks of power, the limits are even lower. The problems are largely economic. And yet much of our coal is far from centers of consumption. For this reason, commercial experiments now under way for pipe line transportation of crushed coal are of fundamental importance. Such transportation would move coal cheaply to electric-power plants, which would convert it to power for nearby customers.

THE CALCULATION OF RADIANT HEAT ABSORPTION IN A FURNACE

IRVING GRANET

THE AUTHOR

Born July 2, 1924, in Brooklyn. Attended Brooklyn Technical High School and received Bachelor of Mechanical Engineering Degree from Cooper Union in 1944. Served two years with Air Corps overseas as Flight Engineer. Employed 1944-45 on Navy Torpedo project as project engineer on stress and vibration studies. Since 1947, employed as project engineer, Research Department, Foster Wheeler Corporation. In June 1948 received Master of Mechanical Engineering Degree from Polytechnic Institute of Brooklyn and in 1949 received Professional Engineers License in New York. At present going to Brooklyn Poly for Doctorate degree and also teaching Thermodynamics in the evening session. Has published several articles on properties of gases.

One of the most complex and difficult problems in the field of heat transfer is the calculation and evaluation of the heat transferred in the combustion chamber of a furnace. Three methods of approach are available by which the solution to this problem may be arrived at. The first method is a theoretical one in which an attempt is made to evaluate all of the various factors involved and treat them according to the well established principles of conduction, convection or radiation as they are applicable. The second approach is empirical in which test data are analyzed in an attempt to isolate those factors of the greatest importance and then establish methods of calculation which will reproduce these test data as closely as possible. The third method that has been used to solve this problem consists of a semi-theoretical approach in which an attempt is made to combine the first two methods noted above. Each of these methods has certain advantages and disadvantages when applied to a particular problem, but in one form or another each or all of these methods have been used with varying degrees of success to many types of furnaces firing different fuels. Of the foregoing three methods, the third has been the most widely used and has met with the greatest success.

Hottel (1), Mullikin (3) and Dwyer (2) have given excellent summaries of methods for calculating the radiant heat absorption in furnaces. They essentially point out that most solutions are based upon a heat balance of the furnace with radiation absorption being assumed to be proportional to the fourth power of an "effective" or "equivalent" radiating

temperature. With this as a basis, the various investigators in this field have attempted to evaluate the pertinent factors and simplify the results. Thus, for instance, the work of Lobo and Evans (4) is available for the analysis of petroleum heaters, that of Orrok (5) for the absorption of heat in the radiant sections of steam generators, and the work of Haslam and Hottel (6) for radiation from pulverized-coal flames. While each of these methods is interesting and valuable it is still the problem of the designer to evaluate them so that he can apply one to the problem at hand.

Hulse and Sarjant (7) have pointed out that the general equation for radiant heat transfer can be given by Equation 1:

$$Q = \sigma A Fw \left[\left(\frac{T_1}{1000}\right)^4 - \left(\frac{T_2}{1000}\right)^4 \right] \times 10^{12} \quad \ldots\ldots\ldots\ldots (1)$$

This is the well known Stefan-Boltzmann relation with several of the factors combined. It is obvious that in order to evaluate this equation several simplifying assumptions based upon both theoretical analysis and test data have to be made. For the source temperature [T_1] involved in Equation 1, Kreisinger et. al. (8), Mullikin (9), Dwyer (2), Lobo and Evans (4), Blizard (10), and Hemenway and Wheater (11) have indicated that the temperature of the combustion gases leaving the furnace is the proper temperature to use. This is especially true when the degree of turbulence of the gases in the furnace is high and the residence time of the gases in the furnace is low. From all of the works cited this is a logical conclusion, but a word of caution must be injected at this point. The temperature of the gases leaving the radiant section of a steam generator as used in this work represents an average value arrived at and justified in the correlative works noted above. Temperature traverses of various furnaces operating with varying types of fuels and methods of firing have been reported in the literature. Of these, several (8), (11), (12) have taken temperature traverses across the outlet opening of the combustion chamber. These traverses have shown that in a very short distance (of the order of several feet) there is as much as four or five hundred degrees variation in the temperature of the gases leaving the furnace. If this is not borne in mind it is possible to design a furnace where serious problems due to this temperature variation may be encountered. This can be especially true where a convection superheater is placed directly following the furnace.

For the temperature of the sink (T_2), many of the previously mentioned workers in this field have used the temeprature of the tubes carrying the fluid being heated. Except for unusually low rates of firing this item can usually be neglected. For instance, Hemenway and Wheater (11) used a value of 1040° R for T_2 with gas temperatures leaving the radiant section of the furnace they were investigating of the order of 2500° R. Neglecting the T_2 term in Equation 1 for these conditions leads to an error of approximately 2½%. At the present state of our knowledge this error is very much less than the other uncertainties involved in furnace calculations. In the same vein, the heat loss from the casing of the furnace may also be usually neglected. This factor has been discussed by Hemenway (13) and as he has noted, "In any event at the normal load the radiation loss should be no greater than 0.2% for a design which is suitably insulated." (the heat losses from a furnace setting are commonly called radiation losses)

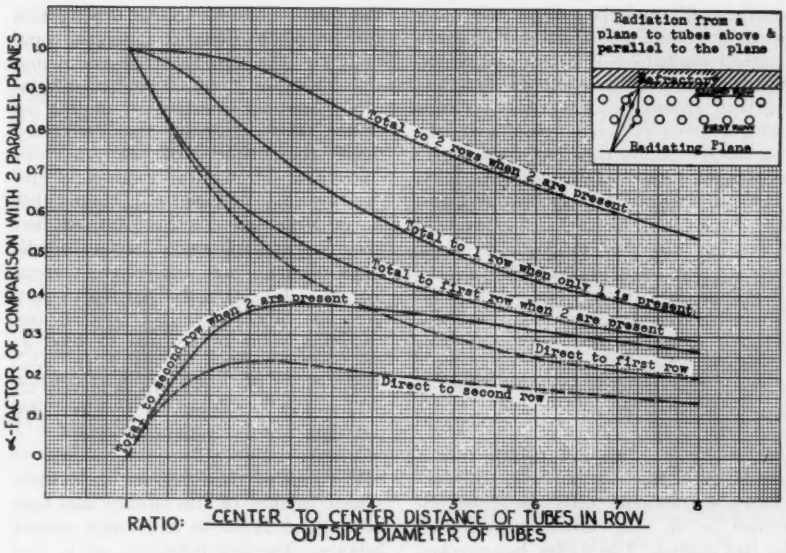
Radiation from a plane to tubes above & parallel to the plane
Radiating Plane
Total to 2 rows when 2 are present
Total to 1 row when only 1 is present
Total to first row when 2 are present
Total to second row when 2 are present
Direct to first row
Direct to second row
∝-FACTOR OF COMPARISON WITH 2 PARALLEL PLANES
RATIO: CENTER TO CENTER DISTANCE OF TUBES IN ROW / OUTSIDE DIAMETER OF TUBES

FIG. 1—Radiation to Tubes As a Function of Tube Diameter and Spacing.

Hottel (14) in 1931 proposed a method of evaluating the effective heat transfer area which is fundamental in concept, easily applied and has been generally accepted. As Mullikin (9) has summarized for the case of a furnace, radiation from the flame source is assumed to be from a plane in front of and parallel to each of the walls receiving radiation. It is further assumed that (for the evaluation of the effective heat transfer area only) all absorbing surfaces are black and that the radiating planes and absorbing planes are infinite in extent. With these assumptions it is possible to evaluate the effective heat absorbing area. Figure 1, based on Hottel's work shows $\propto$ the factor of comparison with two parallel planes as a function of tube diameter, spacing and arrangement. As Mullikin has noted, "$\propto$ is simply the factor by which it is necessary to multiply the projected overall clean waterwall surface (tubes and refractory) in order to obtain the effective exposed radiant surface." For the case of a screen composed of more than two rows of tubes this factor is usually taken as unity. In the usual case the furnace walls will be composed of single row bare tubes backed by refractory. The $\propto$ is then read from the curve of Figure 1, "Total to 1 row when only 1 is present." For unusual tube spacing and arrangements, the factor of comparison can be evaluated either mathematically or graphically as shown by Hottel (14). Dwyer gives a simple explanation of the graphical method and also how to apply this method to evaluation of the radiant heat absorption in a tube as a function of the circumference of the tube.

The evaluation of F_W, in Equation 1 involves the shape, orientation, and emissivity of the tubes, refractory and the flame. Also involved may be the type of fuel, the extent and type of slag

on the walls, and the type of refractory used. It is quite obvious that the mathematical evaluation of F_W can be an extremely involved and tedious task and at best approximate. Because of this several writers have combined the Stefan-Boltzmann constant with F_W to obtain a single value for simplicity. This number [J] is empirical and usually varies from about 800 to over 1713 depending upon the proportions of the furnace, the burners, type of fuel, etc. It is important to note that when using this procedure it is necessary to evaluate J from tests covering all conditions of furnace operation. Even for a single furnace this factor may vary between the limits noted above.

Hemenway (13) has shown that a good correlation of the test data reported by Blizard (10) could be obtained by an empirical relation which he has plotted. The writer has checked this relation and found that this relation corresponds to Equation 1 with J equal to 1060. The unit reported was a marine boiler, oil fired and it had a separately fired superheater. In another instance, from exhaustive tests conducted under the auspices of the American Society of Mechanical Engineers, Hemenway and Wheater (11) found that for a large pulverized coal fired furnace J was 1060 under certain conditions of firing and varied from about 800 to 1200. For the particular purpose of illustration the writer has chosen a value of J equal to 1060 as this value appears to be fairly representative. However this is merely an assumption and must be tempered by test data for the individual case.

With all of the foregoing as a basis a heat balance of the furnace can now be written. Equation 2 is such a heat balance. The left hand

$$1060\left[\frac{T_G}{1000}\right]^4 = \frac{W}{A}\left[K_P + C_F(T_F - 492) + B\,C_A(T_A - 492) - G\,C_G(T_G - 492)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

term represents the radiation absorption as a function of the furnace exit temperature while the right hand side represents the difference between the energy supplied to the furnace and the energy leaving the furnace. As previously noted the radiation losses from the casing are neglected as is the temperature term in Equation 1 which involves the receiver temperature. Since the gases leaving the furnace contain superheated steam which is not condensed the latent heat of the steam formed from combustion of the fuel is not available for steam generation. Thus in Equation 2 the net calorific value of the fuel at constant pressure (the manner in which the fuel is burned) is used instead of the gross calorific heating value at constant volume which one obtains from a bomb calorimeter. The net calorific value at constant pressure is obtained from the gross calorific value at constant volume by subtracting 9125^H, where H is the fraction of hydrogen in the fuel. Similarly the net calorific value at constant volume is obtained from the gross calorific value at constant volume by subtracting 9387^H.

For the purpose of illustrating the use and utility of Equation 2 the writer has selected an oil fired furnace fired with a fuel oil whose analysis corresponds to the one given in the Hemenway paper. From stoichiometric considerations (15) a plot of the variation of CO_2 to excess air with varying percentage hydrogen content in the oil has been made. These relations are shown

in Figure 2. From these same calculations the analysis of the flue gas for various percentages excess air was obtained as were the pounds of air and the pounds of gas per pound of fuel burned. This relation is shown in Figure 4. The temperature of the air entering the furnace was assumed to be 560° R and the temperature of the oil entering the furnace was taken at 610° R. Based upon the tabulation in Hunsaker and Rightmire (16) the specific heat of the oil was taken to be 0.50. The oil selected for this example has a gross heating value at constant volume (by bomb calorimeter) of 18,500 btu/lb. oil. The necessary mean specific heats for the gas and air were obtained from the work of Kobe and associates (17) for each temperature and percent excess air. Figure 3 is a plot of the mean specific heat of the products of combustion (and air) as a function of the upper temperature and the percent excess air.

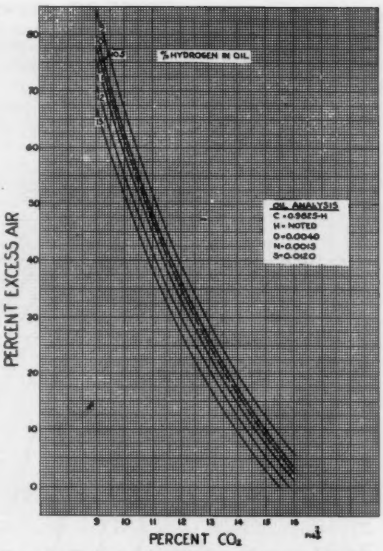

FIG. 2—Relation of CO_2 to Excess Air for Variation in Hydrogen Content for a Typical Fuel Oil.

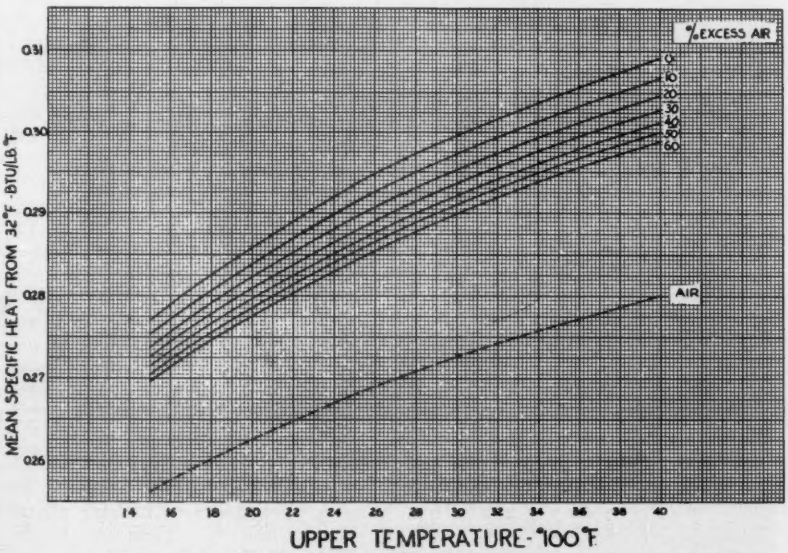

FIG. 3—Mean Specific Heat of a Flue Gas From a Fuel Oil Between 32°F. and Upper Temperature.

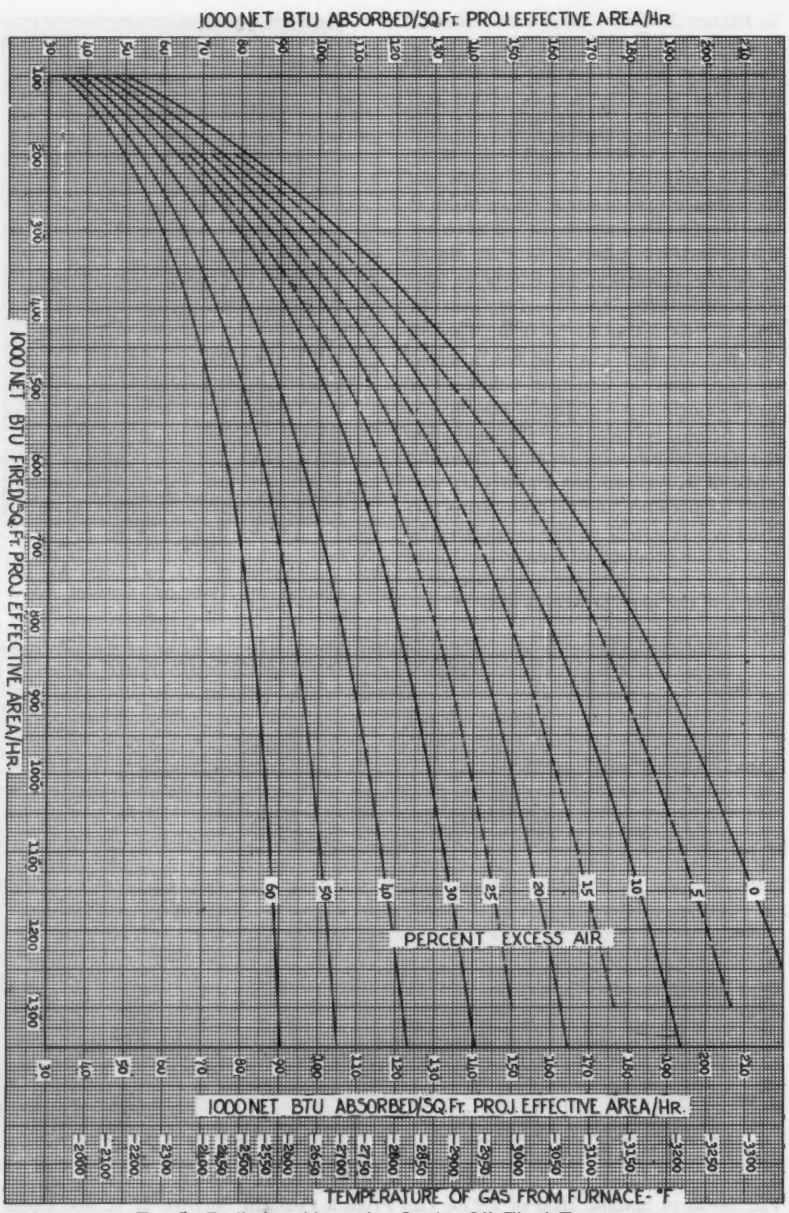

FIG. 5—Radiation Absorption In An Oil Fired Furnace.

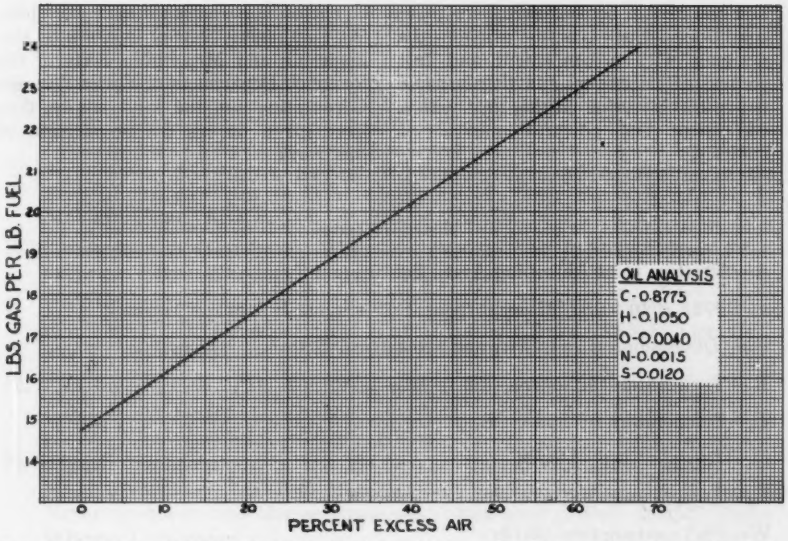

FIG. 4—Relation of LBS. Gas/LB. Fuel for Various % Excess Air For a Typical Fuel Oil.

It will be noted that the evaluation of Equation 2 involves the differences between large and nearly equal numbers. The writer has found that especially at high absorption rates the slide rule does not provide the requisite accuracy for these calculations. Therefore the writer performed these calculations on a computing machine with sufficient places carried from each part of the calculations to insure at least four place accuracy in the final results. Figure 5 is the final plot of the radiation absorption in an oil fired furnace as a function of the net heat fired per square foot of effective projected radiant heat absorbing area and the percent excess air. For convenience the temperatures of the gases leaving the furnace have been noted on this curve. The net heat fired plotted as the abscissa for Figure 5 is the product of the pounds of oil fired per hour and the net heating value at constant volume of the oil. The utility of this curve lies in the fact that once the net effective heat absorbing area has been evaluated, the absorption and the furnace exit temperature can be quickly evaluated for many load conditions. Also this curve can be used if some of the assumptions are changed. For instance, assume that the air entering the furnace is at 300° F instead of the 100° F used to construct the curves. In this case it is only necessary to add the difference in heat content of the entering air above 100° F to the net heat fired and then use the curves as before. Should tests show that for a particular case the value of 1060 used is not correct, it is only necessary to multiply both the abscissa and ordinate by the ratio of the correct value to 1060. Note that if this is done the temperature scale is not to be multiplied by this ratio and remains unchanged.

The analysis used for oil firing above is applicable to other types of firing, such as gas or coal and curves similar

to Figure 5 can be constructed for these conditions. Such curves provide the designer with a convenient and fast method of calculation and they provide the research worker in this field with a convenient and powerful method of analysis.

The author wishes to thank Mr. John W. Cartinhour, Deputy Director of Engineering and Mr. Philip Kass of the Research Department of Foster Wheeler Corporation for the kind advice they have given during the preparation of this work.

Nomenclature

A—Effective Heat Absorbing Area; Sq. Ft.

σ—0.1713×10^{-8} btu/hr sq ft (deg R)^4—Stefan-Boltzmann constant

F_W—Dimensionless emissivity and geometrical factor

T_1—Temperature of source—°R

T_2—Temperature of Sink—°R

Q—Heat absorbed—btu/hr

T_G—Temperature of gas leaving furnace—°R

W—Fuel consumption—lb/hr

K_P—Net calorific value of fuel—at constant pressure—btu/lb

J—a factor varying from about 800 to over 1713

C—mean specific heat of substance between 492°R and t, —btu/lb deg F (subscripts F, A and G denote fuel, air and gas respectively)

T—Temperature at which substance enters furnace—°R (subscripts F and A denote fuel and air respectively)

B—Lb air/lb fuel

G—Total lb gas per lb fuel (includes excess air)

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THE BEHAVIOR OF ROLLING BEARINGS AT VERY HIGH RUNNING SPEEDS

ACKNOWLEDGMENT

This article, written by MR. G. GETZLAFF, was originally published in "Kronstruktion," Vol. 4, No. 9, 1952. It was translated into English and reprinted in the November 1952 issue of "The Engineers' Digest." It gives the results of an investigation of various types of rolling bearings tested at running speeds approaching 100,000 r.p.m., and includes a study of the factors to be considered in the design of bearings for extra-high speed applications.

The development of small-size high-speed blowers and turbines, capable of a remarkably high performance and costing only a fraction of the price of piston machines of similar power, was stimulated by aircraft requirements. This trend is still in its initial stages, but these new machines are already finding a wide variety of applications, for instance as driving units for boiler auxiliaries, and as topping turbines in industrial heating plants, dairies, etc.

Both plain and rolling bearings have been used in these high-speed turbine units, without showing a definite superiority of one type or the other. However, rolling bearings have the advantage of being able to operate with extremely small quantities of lubricant. This decreases the sealing difficulties and frequently results in a simpler arrangement.

TEST EQUIPMENT

The investigation of high-speed rolling bearings was made in two test rigs, in which the bearing to be tested was used at one end of a plain shaft supported in bearings at its two ends. Axial loads were applied by means of a spiral spring and spindle acting on a third ball bearing situated on the shaft. Temperature measurements were taken by means of thermocouples placed at four points on the outer ring of each bearing tested.

The first rig was driven through a change-gear unit by means of an a.c. motor, the speed of which could be adjusted within certain limits. The second rig was driven by a compressed-air open-jet type turbine with infinitely variable speed capable of reaching close to 100,000 rpm. Automatic switches, regulators and indicating devices made it possible to carry out long-time tests under constant conditions without manual adjustment during operation.

The information presented here is derived from tests of Series 62 light-load radial deep-groove ball bearings (for shaft diameters of 10-35 mm) and Serial NL35 radial cylindrical type light-load roller bearings (for shafts of 35 mm diameter) at speeds varying from 20,000 to 70,000 rpm.

DIFFERENT LOADING CONDITIONS OF NORMAL AND HIGH-SPEED BEARINGS

The loading conditions of normal and high-speed bearings are considerably different. "Normal bearings" are designed for minimum friction at relatively low speeds with fairly high external loads. The primary factor is the external load and bearing failures are generally traceable to materials fatigue due to flaking. On the basis of large series of tests, the size and type of bearing to be selected is determined from charts or formulae giving a relationship between bearing life and the specific load considered. The following data, for instance, are reproduced from Jürgensmeyer's curves for normal-speed bearings:—

Bearing type	Bearing load	3500	3000	2000	1500	1000	600	400 kg
"1408"	Shaft revs. before failure	0.05	0.05	0.08	0.1	0.25	0.77	3.8×10^9
"6408"		—	0.03	0.04	0.05	0.1	0.5	$- \times 10^9$

"1408" = self-aligning ball bearing (40 mm diameter).
"6408" = deep groove ball bearing (30 mm diameter).

In high-speed application, the bearing load due to external forces is smaller, since the rated power is obtained with less torque at higher speeds, and the internal loads become more important. The latter are mainly due to centrifugal forces on the cage and the rolling bodies and to sliding friction at high speeds. Both types of loads result in generation of heat, and it can be said that bearing temperature and cage wear are the primary factors for running speed and bearing life. Bearing failures at high running speeds usually occur approximately as follows: during running, the eccentricity of the cage (corresponding to its running clearance) is increased as a result of wear. The bearing temperature is no longer stable, but rises at an increasing rate and causes local overheating. This reduces the lubricating properties of the oil and results in a complete breakdown of the bearing. In some cases, when the bearing is working near the limit of its thermal loading capacity, a breakdown can also be initiated by an additional generation of heat due to external factors, for instance, a decrease in oil flow or an increased power output of the machine.

Having thus outlined the differences in the types of loading, the main factors affecting high-speed bearings will now be considered in detail.

MAIN OPERATING FACTORS FOR HIGH-SPEED BEARINGS

Quantity of lubricant: Temperature stability can be regarded as the basic criterion for bearing loading at extreme running speeds. By varying the supply of lubricant, the bearing temperature can be altered considerably. Fig. 1 shows that by increasing the quantity of lubricant supplied, the bearing temperature is decreased along a curve tending asymptotically towards room temperature. The reverse effect, i.e., a temperature rise following a reduction in oil supply, is not true in all cases. It was found that, when very small quantities of lubricant are used, an appreciable decrease in temperature can sometimes be obtained. Thus, the bearing may run at the same temperature

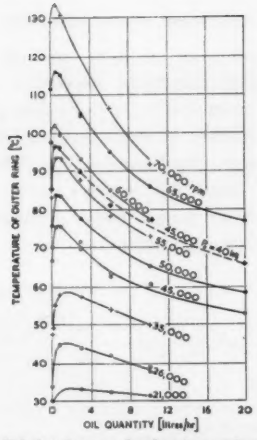

Fig. 1. Relation between bearing temperature and oil supplied, for a deep groove ball bearing No. 6202 (15 mm dia.). Radial clearance approx. 20 μ; radial load $P_r = 0{\cdot}4$ kg; axial load $P_a = 4$ kg. Brass cage guided by inner ring. Indirect air cooling.

with two different rates of oil flow, one of which may be 100 times greater than the other.

This feature is particularly important in applications where a highly effective oil sealing is essential. It would seem that, with minimum quantities of lubricant, the heat generated by hydrodynamic friction (eddy formation) is so small that the bearing temperature is then mainly governed by rolling and sliding friction. This falling-off in temperature is more difficult to obtain with small radial clearances and when the bearing is used at high temperature levels.

It was found that, under similar conditions as regards clearance, load and running speed, roller bearings show somewhat lower temperature rises than deep groove ball bearings of the same size.

Running speed: It was generally found that the temperature increase with running speed follows a linear law when the supply of lubricant is maintained constant. The lines become steeper with higher loads and larger inner diameters. The slope of the lines can be reduced by means of additional cooling which improves the heat-dissipating conditions.

Axial load: An additional axial load produces a corresponding increment in temperature in deep grove ball bearings. This is due to the increased deformation of the rolling bodies and the increased work of the cage in guiding the bearing balls. The effect is fairly small, but is greater if the initial bearing load is already high. It can be said, therefore, that bearings are relatively insensitive to temporary overloads.

A small unidirectional axial load has a favorable effect on high-speed bearings, since it tends to give more stable running conditions by damping out spurious impacts and vibrations. It is a known fact that blower "pumping" under unstable conditions can cause bearing failures. In the present tests, it was found that the no-load tests gave the greatest scatter in the results.

Bearing clearance: Radial clearance has an extremely great influence on the thermal loading of bearings whereas axial and angular clearance alterations showed no visible effects. The latter factors were therefore disregarded. In general, it may be said that the greater the radial clearance, the lower the bearing temperature, under otherwise constant conditions.

It is useful to make the following distinctions in regard to bearing clearances:—

1. Manufacturing clearance: This is the clearance before the bearing is fitted, and in the condition in which it is supplied by the makers.

2. Fitting clearance: This is the clearance after fitting, taking account of changes in shape due to fitting.

3. Running clearance: This is the effective clearance obtained under stable operating conditions after a running-in period.

All the radial clearance values indicated in this investigation are fitting clearances. Fig. 2 illustrates the considerable influence of radial clearance on high-speed bearings. With the NL35 type roller bearings referred to in this figure, a temperature variation of more than 35° C was obtained by altering the clearance from 20 to 30 microns. Bearings with a fitting clearance greater than 20 microns heat up much less than those with smaller values, which are more sensitive to thermal expansion and other influences, such as sideways titling of the rollers and cage recentering action. In deep groove ball bearings the influence of radial clearance is less marked. Running-in changes were not observed. Even after nearly 1500 hours' running at speeds around 30,000 rpm, no measurable increases in clearance as a result of wear were found on the balls and races. Only the cage clearance was somewhat greater. The influence of the type of fit on bearing clearance will be considered in a later section.

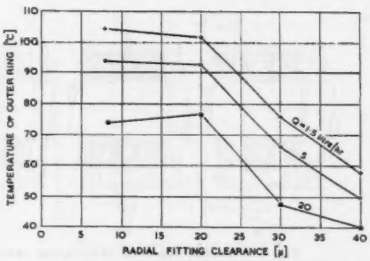

Fig. 2. **Effect of radial fitting clearance on bearing temperature.**
Roller bearing No. NL35; speed 21,000 rpm, radial lord approx. 2 4 kg; very low viscosity oil.

Type and temperature of lubricant: The viscosity of the lubricant is an important factor. Viscous oils result in high bearing temperatures. Even with extremely small quantities of lubricant supplied, a very low viscosity oil will give superior results, in spite of the fact that in this case the amount of heat generated mainly depends on sliding and rolling friction. Tests on an NL35 roller bearing showed that (a) bearing temperature increases approximately as the square root of the viscosity value in poises, and (b) the temperature rises with reduced oil flow but again follows the same type of curve as a function of viscosity. Although oil viscosities decrease hyperbolically with increasing temperature, the temperature variation due to the use of lubricants of different viscosity was clearly noticeable with an oil inlet temperature of 80° C. High oil inlet temperatures result in correspondingly high bearing temperatures, since the temperature difference available for cooling is smaller. This effect of inlet temperature is less marked with small quantities of lubricant and was no longer apparent for quantities below 2 litres per hour.

Tests with grease lubrication were also carried out, and gave satisfactory performance in the lower range of running speeds. According to Bussien, a 16101 type bearing (12 mm diameter) had run over 180 hours at 70,000 rpm with grease lubrication, the temperature rising gradually, after the first 10-12 hours, from about 50° to 60° C, with an axial load of 4 kg. The present tests showed that more favorable conditions for sealing and maintenance can be obtained with grease packing than with oil lubrication, provided that the grease used has a flat viscosity curve and that its dropping point is not too low, i.e., not less than about 120° C. It should also be sufficiently soft at low temperatures. The possibilities of silicones for the lubrication of high-speed bearings are still unexplored and their nearly constant viscosity properties may conceivably lead to interesting results.

Lubricating system: The oil feed arrangement must be designed to ensure that the lubricant effectively reaches the surfaces requiring lubrication. At high rotational speeds, powerful air

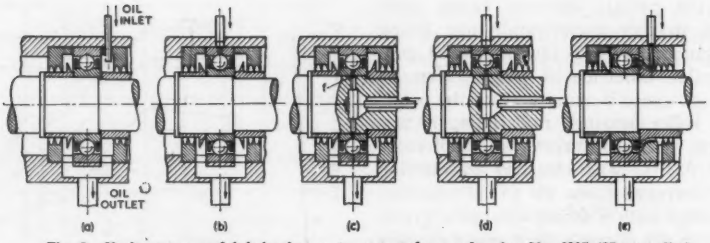

Fig 3. Various types of lubricating systems tested on a bearing No. 6207 (35 mm dia.). (*a*) spray nozzle; (*b*) hole in outer ring; (*c*) holes in inner ring; (*d*) holes in inner and outer ring; (*e*) vane-wheel type.

eddies are generated by the cage and the rolling bodies. These air eddies have a repelling effect on the oil spray projected on the bearing and prevent adequate lubrication. Their action is sometimes so effective that bearing failures inside a lubricating sump can occur, the cause of which cannot be subsequently detected.

Provided that the lubricant actually reaches the bearing surfaces, the type of oil feed arrangement used has little influence on bearing temperature. This was proved by comparative tests of five different bearing designs shown in Fig. 3, which incorporated the following lubricating arrangements:—

Bearing (a): spray nozzle in gap between outer ring and cage;

Bearing (b): oil hole in race of outer ring;

Bearing (c): two holes in race of outer ring;

Bearing (d): two holes in inner ring and one in outer ring;

Bearing (e): oil mist lubrication by means of a small vane-wheel.

These No. 7207 bearings (35 mm diameter) with a fitting clearance of approximately 17 microns were tested at 21,000 rpm with oil supplies of 0.75 litre/hr and axial loads of 4 kg and 120 kg. The bearing temperatures were approximately equal, for all test conditions, for bearings (a) to (d). The best results were obtained with the arrangement of bearing (e), which gives a finer and better distribution and permits transverse ventilation of the bearing.

Spray nozzles arranged as indicated in bearing (a) were found very unreliable in operation. For small quantities of lubricant, very small nozzle holes are required, which can easily be blocked. Delivery at a constant pressure is considerably affected by temperature. Starting conditions are extremely uncertain and with a cold viscous oil even a high pressure may not be sufficient to obtain a satisfactory flow through the nozzle holes.

Oil holes in the annular races gave satisfactory results. However, in the arrangements (c) and (d), the groove *f* in the shaft can be blocked up by heavy dirt particles thrown out of the oil by centrifugal force. The use of these complicated designs is justified only for special applications.

The most favorable overall results were obtained with oil mist lubrication, which is being increasingly used in many applications. Oil mists are always present near meshing positions of lubricated gear teeth, and it is only necessary to ensure that there is an adequate transverse flow through the bearings.

In turbines, an accurate metering of the quantity of lubricant supplied is necessary, and various devices are used for this purpose, such as wicks, porous walls in combination with compressed-air cushions, etc. A 3-mm felt wick, for instance, supplied 20 cm³ of lubricant per hour and this was converted into an oil mist by means of a small vane-wheel with vanes similar to those of a radial blower. The slight excess in pressure generated on one side of the vane-wheel provides for the axial flow of the oil through the bearing. This disc and vane-wheel arrangement can also be used as sealing system against oil mist where fully-effective sealing is required, as in the food-processing industry and in air conditioning equipment. The oils used for mist lubrication must have a high aging resistance and, furthermore, the lubrication requirements under starting conditions must not be overlooked.

Cage material and bearing design: Comparative tests were made of three identically-designed deep groove ball bearings with cages of the following materials: (a) "Bondur" aluminum alloy, (b) brass, and (c) specially-treated wood. Typical results are given in Fig. 4, for two load values (120 kg and 4 kg), with the measured bearing temperatures plotted against the thermal conductivities of the materials.

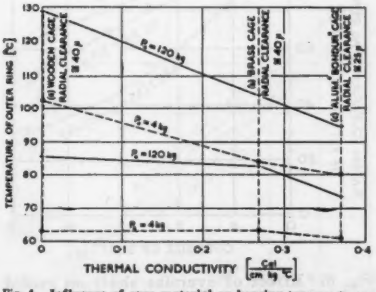
TEMPERATURE OF OUTER RING [°C]
THERMAL CONDUCTIVITY [Cal/cm hr °C]
(a) WOODEN CAGE RADIAL CLEARANCE 0.40 μ
(b) BRASS CAGE RADIAL CLEARANCE 0.40 μ
(c) SPECIAL "BONDUR" CAGE RADIAL CLEARANCE 0.65 μ
P_r = 120 kg
P_r = 4 kg
P_r = 120 kg
P_r = 4 kg

Fig. 4. **Influence of cage material on bearing temperature.** All cages of solid metal, guided by inner ring. Radial load P_r = 2·4 kg; speed: 21,000 rpm; oil supplied: Q = 1·5 litre/hr.

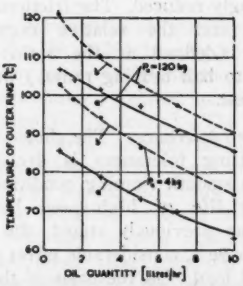

Fig. 5. **Influence of bearing design on bearing temperature.** *a* = 6207 bearing (35 mm dia.), solid brass cage, guided by inner ring; *b* = 1207 bearing (35 mm dia.), solid self-aligning brass cage. Speed 21,000 rpm; radial load P_r = 2·4 kg; axial loads P_a = 4 kg and 120 kg.

The most favorable results were obtained with the aluminium alloy cage, despite the fact that this bearing had a somewhat smaller radial clearance than the other bearings. Its curves of temperature against quantity of lubricant also give the lowest values. At high loads, the wooden cage shows definitely inferior thermal properties, owing to the greater deformations and the insulating effects of wood.

Fig. 5 gives a comparison of a self-aligning bearing No. 1207 with a solid brass self-centering cage and a No. 6207 deep-groove bearing having a cage made of solid brass, and guided by the inner ring. The self-aligning bearing, in spite of its slightly greater clearance, reaches the higher temperatures, because of its less favorable cage centering and 2.8 times greater number of rolling bodies. At increased loads, however, the temperature difference is much smaller, as a result of smaller deformations with the larger number of balls and better lubricating conditions as regards rubbing.

A considerable amount of information can be gained by testing cages of various types. It would be interesting, for instance, to compare bearings of Series 160 and 60X, which have much lower cage sliding velocities while the heat-dissipating surfaces are not corre-

spondingly reduced. The frictional conditions and the relative degree of contact (defined as the ratio: track radius to ball bearing radius) are also important.

Fitting tolerances: The choice of correct fitting tolerances is decisive as regards smooth running conditions and bearing life of high-speed bearings, since, as previously stated, the clearances have a considerable effect on the thermal load. On the basis of the tests carried out, it is recommended that the radial fitting clearances should not be less than the values given in the following table.

MINIMUM VALUES FOR RADIAL FITTING CLEARANCE

Bore	10 mm	20 mm	35 mm	Roller bearings 35 mm
Clearance	15 μ	20 μ	30 μ	30 μ

These values are valid for bearings completely assembled and fitted. It should be noted that the nominal clearances quoted by the bearing makers can be reduced by the following factors during assembly and operation:—

(a) widening of the inner ring due to oversize shaft;
(b) distortion of the outer ring if this is slightly oversize relative to the inner diameter of the housing;
(c) changes in shape and length during operation, as a result of unequal heating of components (for instance, in gas turbines);
(d) widening of the inner ring during running, caused by the action of centrifugal forces.

A rule valid for all rolling bearings is that a tight fit should be obtained for the race which rotates relatively to the direction of the load, whereas a loose fit can be used for the other ring. Generally, the inner ring has a tight fit. The amount of interference to be allowed for the shaft and its effect on bearing clearance thus need to be considered, in connection with the standard fits given in the ISA specifications.

The widening of the inner ring caused by an oversize shaft has by far the greatest effect in reducing bearing clearance, and curves indicating the order of magnitude of this effect for two types of bearings are shown in Fig. 6. The solid line, referring to a ball bearing No. 6207, shows that with a shaft interference of 10 microns the radial clearance is halved. The dotted lines obtained from measurements on two NL35 type roller bearings show less marked effects. These curves indicate that the reduction in clearance is approximately equal to 80 percent of the shaft interference for NL35 bearings, and even greater for 6207 type bearings. Similar results can be expected for other sizes of bearings.

Normal rolling-contact bearings are unsuitable for very high speeds, their radial clearances being far too small. For 10 to 35 mm inner bearing diameters, for instance, Jürgensmeyer gives directional constraint values of 4-18 microns, and for these figures manufacturing clearances of 20-50 microns are necessary.

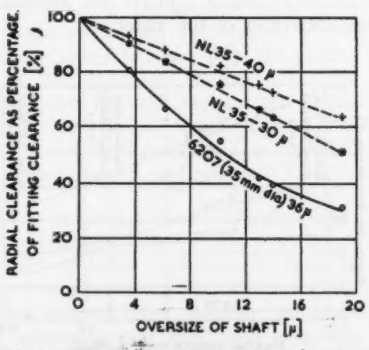

Fig. 6. Effect of oversize shaft on radial fitting clearance of some bearings tested. (Numbers indicate radial fitting clearance in μ).

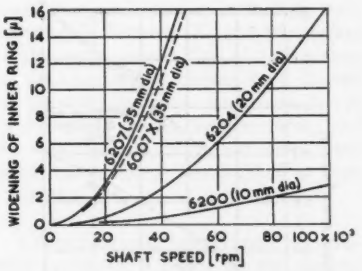

Fig. 7. Widening of the inner ring diameter of various sizes of bearings owing to high running speeds.
(Based on data from " Hütte," Vol. 1, 27th ed.)

The fit to be provided for the inner ring depends on the magnitude of the external load and the accelerations. Generally, it is possible to use a looser fit than is usual at lower speeds. The lower interference limit can be determined by taking account of the widening (already referred to under (d) above) of the inner ring under the action of centrifugal forces (see Fig. 7). When this value is subtracted from the shaft diameter, the interference of the shaft must still be sufficient to prevent slipping of the ring. For this, values of 2-4 microns are sufficient, on the basis of experience with aero-engine blowers.

It is necessary to relate bearing tolerances to the ISA specifications for rolling bearings. For instance, in the case of a No. 6204 bearing of 20 mm diameter, the requirements for the inner ring are nearest related to the fitting tolerances j5, j6 and k5. The k-group always ensures a solid fit but large oversize values may result in some cases. The j-group generally gives less powerful adhesion between inner ring and shaft, and when a maximum size for the inner ring coincides with a minimum diameter, the fit may be too slack. It is thus frequently necessary to take intermediate values. The ISA tolerances can be modified to apply to high-speed rolling-contact bearings. DIN 620 provides finer tolerances on the basis of an additional two-figure "C" classification. This classification has been expanded by Mundt and the main features of this developed system are reproduced in the tables given below. The fit of the inner ring is determined by the designations C-1-0, C-2-0 and C-3-0. The inner tolerances are restricted by C10 to values in the middle of the tolerance range, while C20 restricts towards the rejection size and C30 towards the acceptance size.

To characterize the bearing clearance, an additional one-figure "C" classification was developed. This can be used either alone or in conjunction with the previous two-figure classification, which then becomes a three-figure system.

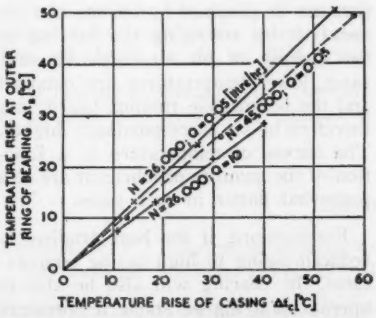

Fig. 8 Effect of additional heating of casing on temperature of a bearing type 6202.

MUNDT'S TWO-FIGURE "C" CLASSIFICATION FOR ROLLING-CONTACT BEARING

No.	First figure: SIZE ACCURACY	Second figure: RUNNING ACCURACY
0	Normal	Normal
1	Increased fitting accuracy	Increased running accuracy of inner ring
2	Closer inner diameter tolerances on the rejection side	Further increase in running accuracy of inner ring
3	Closer inner diameter tolerances on the acceptance side	Increased running accuracy of outer ring
4	Closer sleeve tolerances on the acceptance side	Further increase in running accuracy of outer ring
5	Closer sleeve tolerance on the rejection side	Running accuracy as, under 1 and 3

ADDITIONAL ONE-FIGURE "C" CLASSIFICATION FOR BEARING CLEARANCE (AFTER MUNDT)

Additional figures	Bearing clearance
C1	smaller than C2
C2	smaller than normal
—	normal
C3	greater than normal
C4	greater than C3
C5	greater than C4

Examples: 6204/C3 = bearing with increased clearance.
6204/C213 = bearing with closer inner diameter tolerance on the rejection side + increased running accuracy on inner ring + increased bearing clearance.

The tolerance limits given above are also valid, with appropriate modifications, for the less frequent case of a solid fit required on the outer ring. The outer ring is more sensitive to seizure and distortion, so that with a solid inner ring fit, a looser fit for the casing inner diameter can be provided (corresponding to ISA fits H7, H6 or J6).

The effects of temperature on clearance are so small that generally no extension of the classification will be required. If in accordance with Merkle it is assumed that the inner ring temperature is about 30° C above that of the outer ring, this would give an additional linear expansion of 0.5 micron for the inner ring. Temperature effects become much more important where the bearing is exposed to external heat at a high temperature level (as in exhaust gas turbines). It is then essential to avoid unequal temperature distributions by means of special precautions in the design.

The tolerances to be prescribed for shafts, casings and rolling bearings vary with each application and must be carefully considered. The fitting of "C" class bearings signifies an appreciable increase in costs and prices and for this reason a compromise between the user's requirements and the possibilities presented by the makers will be necessary in most cases. In extreme cases, some tests will always give the best answer.

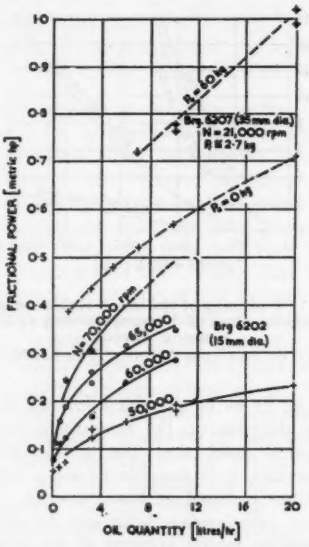

Fig. 9 **Power dissipated in bearings as a function of quantity of lubricant and speed, for two 62-Series bearings. Very low viscosity oil.** (Based on data from Getzlaff, v.d. Nüll and Pfau).

Operating temperature: The bearing temperatures indicated above are only qualitative values. According to the type of assembly, increased heat dissipation can be obtained by the use of light metal or by arranging the bearing in the vicinity of an air flow. In such cases, lower temperatures are obtained and the permissible running speeds can therefore be set correspondingly higher. The curves of temperature as a function of the quantity of lubricant are also somewhat flatter in such cases.

Furthermore, if the heat gradient is reduced owing to high casing temperatures, the bearing will also be able to operate at a higher stable temperature value. In the tests (see Fig. 8), it was

found that the increase in bearing temperature is between 72 and 93 percent of the temperature rise of the casing. In the diagram of temperature against oil quantity, the curve rises more steeply for high casing temperatures, and the reversal and falling-off with minimum lubrication is less marked or nonexistent.

The permissible temperature for long-time operation depends on the thermal behavior of the bearing materials and the lubricants used. The hardness of the bearing races starts decreasing gradually at temperatures above 160° C. As the temperature of the inner ring may be taken to be 30° C higher for high-speed bearings, it can be concluded that the temperature measured at the outer ring should be limited to approximately 130° C. Higher values are permissible in the case of low bearing loads.

Frictional power: Approximate figures regarding the power dissipation of high-speed bearings are given in Fig. 9, for bearings of types 6202 and 6207. The curves show power dissipated as a function of the quantity of lubricant for various running speeds and are based on power measurements or calculated from the measured temperatures.

COMPARISON OF BEARING LOADS

Frequent use has been made of a "speed factor" in assessments of bearing loads of high-speed rolling bearings, both for comparison purposes and for extrapolations. This factor is defined as

$$g = N\, d_m$$

where N is the running speed, in rpm, and $d_m = 0.5\ (d + D)$ the mean bearing diameter, in mm. For deep groove ball bearings with a guided bronze cage g-values up to 900,000, and for special cages values as high as 2,000,000 have been indicated. The "g" factor is based on the assumption that two bearings of the same basic design but of different size can both be run safely at running speeds determined by the speed factor. The calculation is: $N_2 = N_1 d_{m1}/d_{m2}$.

As bearing temperatures are extremely sensitive to a great many factors, it can be concluded that the speed factor is not a criterion which is applicable over wide ranges of values. Plots of outer ring temperature against shaft rpm for various quantities of lubricant show curves with different slopes for similarly-designed bearings of different diameters. The slope also varies somewhat with the external load, and other factors. Thus, it may be said that even a rough assessment on this basis is not attainable. It is hardly possible to apply test results of one bearing to another bearing of different diameter or design without taking account of the major factors, viz. clearance, lubrication, heat flow, load, geometrical and mechanical similarity. As a rule, a test will be the more rapid way of obtaining a reliable answer.

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THE USE OF STATISTICS IN PLANNING LABORATORY AND FLEET TEST WORK

BESSE B. DAY

(ILLUSTRATED BY R. W. MILLER)

THE AUTHOR

B.S. Mathematics, Mo. State College, Warrensburg; M.A. Mathematics and Statistics, University of Michigan, 1927. Worked thereafter principally in the application of statistical techniques in research, development and quality control of production in the fields of engineering and forestry. 1927-29 Victor Talking Machine Company; 1930-42 U. S. Forest Service; 1943-47 The Johns Hopkins University Applied Physics Laboratory, on the development and production of the radio proximity fuze; 1947 to present, head of Statistician's Office and member of Engineering Council, U. S. Naval Engineering Experiment Station, Annapolis, Md. Fellow American Statistical Association and American Society for Quality Control; Executive Committee of Physical Sciences, A. S. A.; Director of Middle Atlantic Region, American Society for Quality Control. Published other writings and given papers on applications of Statistics to engineering.

INTRODUCTION

The word "Statistics" to a nonstatistician usually implies survey data such as the Census Bureau would collect and summarize. Be assured that such a meaning has *no* part in what will be discussed herein. Oswald George, a British Statistician, has aptly said, "When I was younger, Statistics was the Science of large numbers. Now it seems to me, rapidly, to becoming a science of no numbers at all!" Numbers will be the least part of this paper.

BACKGROUND FOR STATISTICAL PLANNING

The need for control in test work is well appreciated. In fact, management problems are mainly concerned with means of such control as the purchase of finer instruments, sufficient personnel, etc. It is also appreciated that not all of the factors entering into the test can be controlled. There will always be a multitude of factors, each small in effect, which cannot be controlled. They may be due to environment, equipment, operation, etc. These are the cause of variation in test data.

Variation is always present in all work. Absolute answers can never be found. Variation must be lived with. (Fig. 1)

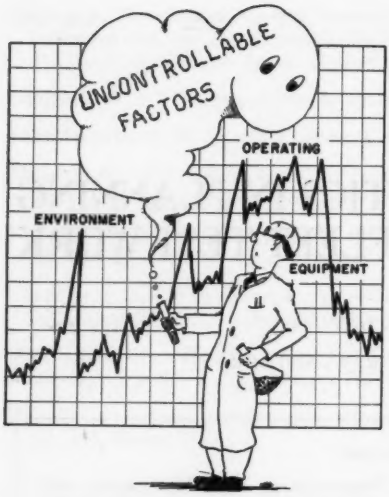

FIG. 1—Variation in Test Work.

Statistics is concerned with pertinent methods for dealing with this variation. By providing an actual numerical measure of the uncertainty, management is no longer forced to arbitrate differences among the technical staff as to the meaning of the test results. Using statistics, the conclusions are arrived at from a purely objective basis. Even the inexperienced engineer will be able to furnish the valid conclusions inherent in the data.

It will be recalled what an important place Statistical Quality Control had in furnishing the Armed Services with the wherewithal to successfully fight World War II. The Standard Military Sampling Tables in general use in present day defense buying attest to the general acceptance of these methods. Industry parallels this use. (Fig. 2)

STATISTICS – THE SCIENCE OF VARIATION

STATISTICAL QUALITY CONTROL

CONTROL CHART
SAMPLING ACCEPTANCE INSPECTION

Mil. Standard 105A
Milwaukee Ord. Depot, $50,000 per year saved
Gillette Razor Company
Norton Company
International Harvester Company
Hamilton Propeller Company
Steel Industry
Paper Industry
Textile Industry
Automotive
Electronics
Glass
etc
etc

SCIENTIFIC APPROACH TO EXPERIMENTATION

EXPERIMENTAL DESIGN (STAT. PLANNING)
EVALUATION OF TEST DATA

Piston Ring Wear
Paints and Enamels
Evaluating Camouflage Measures
Control of High Tensile Steel
Lubrication Problems
Electronic Tube Development
Flame Radiation Performance
Noise Testing of Gears
Evaluation of Generator Set
Chromium Plating Studies
Corrosion Studies
Evaluating Bearing Materials
Hot Hardness Welding Specifications
etc
etc

FIG. 2—

There is now available another special kit of statistical tools, evolved within the last 25 years, for the purpose of handling variation in test work, which is rapidly supplanting the traditional one-factor-at-a-time philosophy of testing.

At the same time that Dr. Walter Shewhart and his co-workers at the Bell Laboratory were engrossed in developing Statistical Quality control methods for controlling the quality of production in industry, and for inspection of materials, parts, and finished products, Professor R. A. Fisher in England was evolving these principles of experimentation for more effective research and development, whatever the field.

This science of experimentation accomplishes two major tasks: One, increases the reliability of the answers (that is, reduces the band of uncertainty about the estimate, and two, reduces the amount of testing required). Since this is such a large order, cheaper and better at the same time, all concerned with experimentation will be interested—more reliable results at minimum costs is a common goal.

Essentially, there are two parts to this science. The first is concerned with *how* the data are collected—statistical planning, in statistical parlance "Design of Experiments." This will be the main theme. The second has to do with the analysis and interpretation of the data. The importance of this phase cannot be too strongly emphasized. However, it is completely dependent upon how the data were collected. Unfortunately, it has been a common practice for the investigator not to worry about the interpretation of the results until after the experiment has been run, only to find himself overloaded with data which did not give an answer to his problems. Advance planning must be done to insure that the test data will give the answers. This lack of planning can be devastating in both laboratory and shipboard test work.

The heart of the scientific approach to experimentation has been aptly expressed by Dr. Condon. "In science, as well as in business, it pays to stop and figure things out in advance." This is statistical planning—whereby all possible factors of a test are integrated into a single coordinated plan. Attention is paid to the order or scheduling of the test runs, as well as to the sampling problems involved to assure valid results. By this realistic approach, the initial experiment is likely to be final in contrast to a "long series of meanderings."

You who are experienced in making investigations will appreciate that much of what is said is no more than ordinary common sense. What the statisticians have done is to systematize this common sense into a pattern equally applicable to experimentation in all scientific fields.

A very simple example will be used to demonstrate the principles of statistical planning and to show the advantage of this approach over the traditional one-factor-at-a-time method. A few of the many types of problems where statistical planning was successfully applied will be pointed out. To be frank, this is an attempt to sell you Statistical Planning.

The example selected concerns diesel engine fuel, a subject of interest to all.

PRINCIPLES OF STATISTICAL PLANNING

It is no secret that the United States must make a high bid for Near (Middle) East fuels should a major crisis arise. Even now some 1,300,000 barrels are being delivered to the Navy for almost exclusive use this year on the West Coast. But, because these fuels are of high sulphur content, a major

problem is created, manifested in the severe wear of working parts, greater corrosion of the nonworking parts, increased sticking of piston rings, and dirty engines. This may mean high repair and replacement costs. It is, therefore, important to the Navy to study the effects of different content of sulphur in the fuel and to try to devise means of combating the detrimental effects.

A preliminary phase of this problem might be a laboratory test to compare the effects of two fuels of different sulphur content, one very high sulphur content, the other somewhat lower. Hence, the purpose would be to find if there is any difference in the effect of the two fuels, and if so, to measure how big the difference is.

Under the traditional method for running a test, as followed by those certain private contractors mentioned at the beginning, the investigator would study only one factor at a time—in this case it would be the effect of sulphur content in the fuel, high sulphur against low. He would hold all other factors constant and vary the one, hoping to be able to keep the test conditions in control throughout the entire test.

He would start the test by getting a "good" estimate for the high sulphur fuel under normal operating conditions. He would appreciate the need for more than one run. If the cost were high, he might be able to make only one run with a check run. However, for the sake of the demonstration, let it be assumed in this case that four runs were reasonable. When he has finished the high sulphur runs, he would change to low sulphur fuel, and repeat the number of runs. Thus, for the two fuels, he would have a total of eight runs.

He would then want to try out other things, as the effect of putting an additive into the lubricating oil, repeating the test under snorkel conditions, etc., etc. His second series might be an investigation of operating conditions, so he would make the four runs, low sulphur fuels under snorkel, and the four runs high sulphur fuel under snorkel. He would then have a total of 16 runs. There might be other series if the money holds out.

Thus, there would be four successive runs with high sulphur fuel, all other factors held constant, and four successive runs with low sulphur fuel under what was hoped to be the same constant conditions. A variety of different measurements would have been taken. The number of stuck rings will be used here for illustrative purposes since this would seem to be the simplest. The particular values entered are hypothetical. Therefore, evidence from the data should not be taken seriously.

For the high sulphur fuel, the four readings are 8, 10, 8 and 12, a total of 38 and an average of 9½. For the low sulphur fuel, the four are 7, 9, 10 and 10, a total of 36, and an average of 9. On the basis of these data there would be little or no indication that sulphur content of the fuel affected the tendency of rings to stick.

However, the engineer would most likely not be altogether happy over these results. Since they were not decisive, he might even decide to take some more readings. Regardless of how well-controlled his test was set up, he does know that there will be numerous uncontrollable factors which would introduce errors into the test readings. Some of these could very well correspond to a regular pattern in the material, process, etc. The wear in the engine with use might be an example. This effect might become progressively accentuated as the testing continued. Thus, what statisticians term *bias* would be introduced in the readings. (Fig. 3). A bias, in the statistical sense, does not pertain to an intentional influence on the data. Here, with all of the readings of one fuel completed before taking those for the

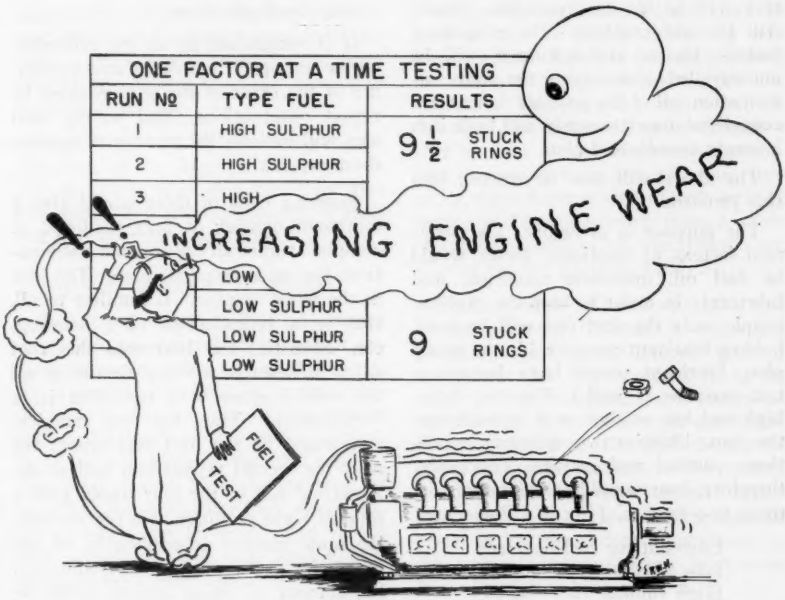

FIG. 3—One-Factor-At-A-Time Method of Testing.

second fuel, the effect of wearing in the engine could have been reflected in the readings of one fuel, thus hopelessly entangling a difference due to fuels with uncontrollable changes in test conditions. A systematic bias would be present. Thus, if the effect of progressive engine wear could have been measured and accounted for, the readings of low sulphur fuel could well have been 5, 6, 6 and 5, respectively, instead of 7, 9, 10 and 10, as given. There would also need to be some adjustment in the high sulphur readings. However, because of the order in which the readings were taken, there would be no possible way of evaluating the adjustments for either fuel. What is true for this comparison will be even more so later when he attempts to use these two averages as standards against later testing, where uncontrollable factors may have caused considerable changes in test conditions. This situation makes it impossible to get a real measure of the error of the test, which is needed in all testing.

This test will now be planned statistically.

Step 1—*The Scope of the Test:*

The basis for preparing a statistical plan is two-fold. First is a concise formulation of the problem—that is, a clear definition of the engineering aims. This must be kept foremost in mind to insure that the test results can be used as intended. To insure that the test data will answer the problem, the procedure to be followed in analyzing the test data will be laid out before starting the test work.

The second important phase in the preparation of a plan is the use of background information which the investigator has accumulated. The numerous factors which may affect the results are listed. A decision is made as to the role that each shall play. The important fac-

tors will be the test variables, others will be held constant. The remaining factors, known and unknown, will be uncontrolled. Thus, using the above information, all of the possible factors are considered simultaneously and built into a single coordinated plan.

The above will now be worked into this problem.

The purpose is as before. The pertinent factors, as mentioned above, would be fuel oil, operation condition, and lubricant. In order to keep the problem simple, only the first two will be used, holding lubricant constant. (In the actual plan, lubricant would have become a test variable as well.) The two fuels, high and low sulphur, will be built into the plan; likewise two operating conditions, snorkel and surface. There are, therefore, four possible combinations of these two factors. (Fig. 4) These are:

Low sulphur fuel—surface
Low sulphur fuel—snorkel
High sulphur fuel—surface
High sulphur fuel—snorkel

Step 2—*Replication:*

It is recognized by all the reliability of the answer is increased and a measure of the error of the test provided by repeat observations. And so the next step will indicate the manner of making these repeats.

Running each of these would give a minimum number of four readings. A complete run of all the possible combinations has an appropriate name. The idea in the word "replica" is familiar to all, that is, a reproduction of a painting, etc. Statistics has borrowed this root word to describe a complete run of all the combinations in a test, that is, a "replication." Thus, the first complete run would be the first replication, the next the second replication, and so on. A second run of the four would give a total of eight readings, two replications, the same number as previously, by the one-factor-at-a-time scheme. Ordinarily, the amount of repeat testing would be based on previous information as to the

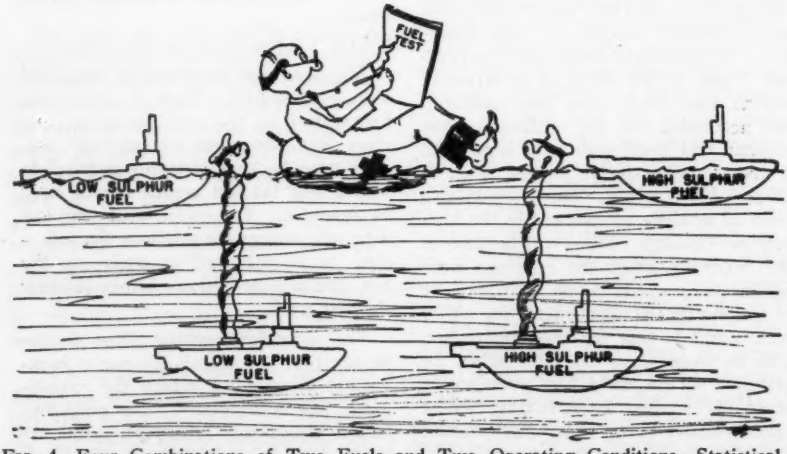

FIG. 4—Four Combinations of Two Fuels and Two Operating Conditions—Statistical Planning.

inherent variability in the test plus the cost involved. Lacking known information, a guess would be made and later revised or affirmed from the results in the testing to date.

Here there will be two complete replications of the four combinations. It will be shown later that there are also two extra "hidden" replications of each fuel and operating condition.

Step 3—*Restrictions (Controls):*

By the one-factor method an attempt is made to control test conditions throughout the entire period of testing. By statistical planning, it is necessary to control the test conditions, within only small parts of the entire period. Here all four runs of the first replication were tested as close together as possible. Not until after they were completed were any of the second set of four tested. It does not matter how much change may occur between the two replications, for such changes can be evaluated and eliminated from the error of the test. In fact, by running the test in two independent replicates of four each, instead of eight together, the experimental error may be definitely smaller. The reliability of the results can, in many instances, be greatly increased by the use of restrictions or controls. This is the basis of many ingenious experimental designs now available. While these designs result in considerable savings this is not the place to go into those details.

Step 4—*Randomization:*

It is only after all of the pertinent factors have been accounted for by careful planning that consideration is given to the uncontrolled factors. As has been emphasized, it is known that there will be uncontrolled factors present to cause variation in making any series of runs. One such factor in this problem is engine wear. To avoid bias in the results, the ideal would be to allot these effects among the several individual runs in such a way as not to favor any one over another. There is no exact method for doing this since many factors are unknown. Therefore the way would be to select the order of run by chance—that is, in a random manner—as numbers drawn from a hat, the four face cards dealt from a well-mixed deck of cards, or the order read from a table of random numbers, of which there are several for this purpose. (Fig. 5)

This principle of randomization, one of the essential features of statistical planning, must be an integral part of every test for the conclusions to be valid. It does two things, it is insurance against bias in the results for particular factors and makes valid the computation of the numerical measure of the random variation called experimental error. Being able to estimate his experimental error is of tremendous importance to the meticulous investigator who must know how good his answer is.

Just how the randomizing operation enters into the plan of a test depends upon the basic information furnished by the investigator as to conditions peculiar to the particular investigation. An

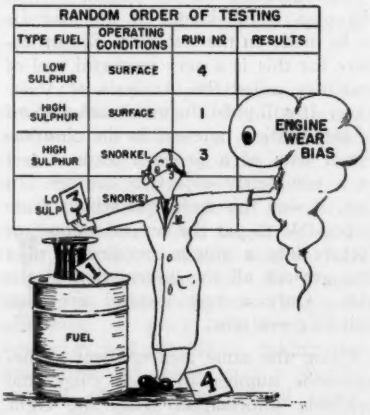

FIG. 5—Random Selection.

important consideration in this respect would be the cost involved. Experience has shown that the requirements for randomization can be fulfilled at little or no additional cost.

In this example, the random selections were made by assigning the numbers 1 to 4 to the four combinations and making two independent draws from a table of random numbers. Below are the two orders actually gotten (the numbers to the right are test data):

Order of Testing	First Replication	No. Stuck Rings
1	Low sulphur, surface	4
2	High sulphur, surface	5
3	High sulphur, snorkel	8
4	Low sulphur, snorkel	6

Order of Testing	Second Replication	No. Stuck Rings
1	High sulphur, snorkel	12
2	Low sulphur, surface	5
3	Low sulphur, snorkel	7
4	High sulphur, surface	7

Thus, there are two complete replications or repeats with the order of testing randomized within each.

Step 5—*Information Available From Test:*

As stated before, an integral part of the plan is the layout of the analysis to be made on the test data. The procedure for this is a very powerful tool of statistics called the Analysis of Variance. It will yield the maximum amount of information inherent in the observational data of a properly-planned test in a completely objective manner. In fact, it was this technique which made it possible to put the several important factors into a single coordinated plan and get out all the information in the data. Only a very general approach will be given now.

Using the same measurement as before—the number of stuck rings, the available information from the eight readings will be outlined.

(a) "Experimental Error."

The first piece of information would be the experimental error, that is, the error of the test. This is needed for it is the tape measure by which the numerical differences between fuels, etc., can be judged real or no more than to be expected from random variation.

There were two readings made at each of the four conditions. The difference between these two readings, with a little arithmetic, will yield us a measure of the uncontrolled element of variation—that is, the "experimental error." This error of the test would be the basis for judging whether the differences for fuels, operating condition, etc., mean anything.

(b) Comparison of Fuels.

The next items of interest would be the two fuels. There were two runs of high sulphur fuel at snorkel, two runs at surface, likewise two runs of low sulphur at each of these operating conditions.

These can be arranged in tabular form, adding the two in each case from the two replications.

No. of runs		Total no. rings stuck
2	high sulphur, snorkel	20
2	high sulphur, surface	12
—		—
4		32

No. of runs		Total no. rings stuck
2	low sulphur, snorkel	13
2	low sulphur, surface	9
—		—
4		22

Here the fuels are balanced as to operating conditions, each having two runs at snorkel and two at surface. Therefore the difference between the two totals will be due to the fuels except for the error of the test which is always

present. Here the difference is $32 - 22 = 10$. This amount would then be compared to the tape measure computed as "experimental error." This will tell us whether the two fuels have an inherently different effect on rings or whether the observed difference is due only to the uncontrolled elements in the test.

Note that the two averages from these totals of four are equally as good as were those by the one-factor-at-a-time, because they were both based on four readings. This illustrates a very favorable characteristic of this method of planning. As previously mentioned, hidden replications are available. While there were only *two* complete replications of the conditions the estimate of each fuel here is based on *four*.

Each additional factor introduced into an experiment means additional replications of the factors already in the test; thereby increasing the precision of their estimates by hidden replications. This multiplies rapidly with several factors.

(c) Comparison of Operating Conditions.

The effect of operating conditions can also be compared because they are balanced as to fuels. This would be the total of the first row in the table above against that for the second row, using the same set of data. Again these totals of operating conditions are based on four readings each. The difference between these over and above random error will be due to operating conditions. The difference here is 12. Applying the same reasons as for fuels, the significance of this difference would be available. This was not available from the eight readings of one-factor-at-a-time test.

(d) Interaction.

But that isn't all. A third piece of information is available. That is whether the high sulphur fuel is equally detrimental at both operating conditions. Thus at snorkel the difference was seven $(20 - 13 = 7)$, while at surface the difference was three $(12 - 9 = 3)$. The excess at snorkel is then four $(7 - 3 = 4)$. Whether or not this value of four represents a real difference in effects depends, as in the other comparisons, on the value of the experimental error. This kind of information is called *interaction*. There is an interaction when the effect produced by one factor is modified by changes in the other. Here, it would be that the increased effect of high sulphur fuel over low sulphur in causing rings to stick is accentuated under snorkel conditions. It can be said that there is a joint or interaction effect of fuel and operating condition. Again this information would not have been available from the first way of testing.

The advantage statistical planning has in furnishing a means of measuring the interacting effect of two factors cannot be too strongly emphasized. Often in engineering development work information as to the possible interactions of the factors will be the most important item. For example, noise may not increase when running at a low speed with changes of the temperature of the lubricating oil, while at high speed the effect may be radically different as temperature changes.

Since the two replications are completely balanced as to fuel and operating condition, the difference in their averages, over and above random error, will be due to replication. Such a difference would be caused by large changes in test conditions, which might be associated with length of time elapsed, such as engine wear, temperature, instrument change, etc. This comparison might be substantial. If there had been a real change in test conditions, taking this comparison out would give a smaller estimate of the experimental error. Thus, the smaller the experimental error, the more sensitive will be the

test, for then, smaller real differences between means can be detected. This is one very important way of increasing the reliability of a test, quite unknown and impossible to the one-factor-at-a-time investigator. Thus, the total of first replication, minus the total of second, would be $(4 + 5 + 8 + 6) - (12 + 5 + 7 + 7) = 23 - 31 = -8$. As in previous comparisons, the importance of this difference will be measured against the experimental error.

At this stage, we can recapitulate our information from these eight readings.

	Comparisons
Replication, first vs. second	1
Fuel, high sulphur vs. low sulphur	1
Operating condition, snorkel vs. surface	1
Fuel by operating condition, interaction	1
Experimental error	3

ADVANTAGES IN STATISTICAL PLANNING OVER ONE-FACTOR-AT-A-TIME METHOD

Stock may now be taken on the two ways of running a test, basing it on eight pieces of data in each case.

RESULTS FROM EIGHT RUNS BY EACH METHOD

One-Factor-at-a-Time	*Statistical Planning*
Averages of the two fuels based on four readings possibly entangled with biases from changes in the test conditions.	Averages of two fuels based on four readings free from bias.
	Average of effect of two operating conditions based on four readings free from bias.
And that is all.	Interaction effect evaluated of fuel and operating condition.
	A measure of experimental error.
No real basis for conclusion.	Broad base for conclusion. (High sulphur fuel under different operating conditions.)

The remarkable difference in the information available from the two methods of running the test is certainly a selling point for the scientific approach. By the one-factor-at-a-time method the investigator ends up with very unsure, unstable results. The uncontrolled factors have introduced bias and have completely spoiled the measure of the experimental error. (Fig. 6) On the other hand, with statistical planning, a single coordinated plan is followed which makes it possible to measure the experimental error and furnishes him the results in a beautifully tied-up package. (Fig. 7)

For purely demonstrational purposes, the example was limited to two factors each at two levels. As the number of factors and the levels of each increase, the advantages of statistical planning multiplies progressively. In this example, lubrication should have been included say at two levels—low additive

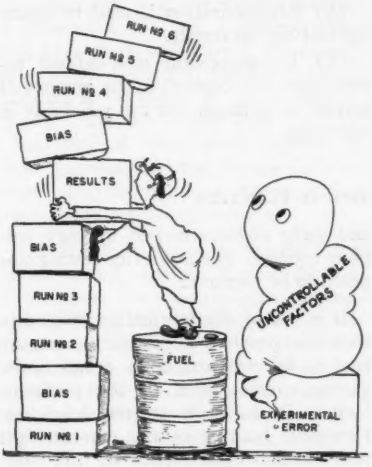

FIG. 6—Results With One-Factor-At-A-Time Testing.

and high additive—at the same time, since information was becoming available on what high sulphur fuel was doing to the engine, preventive measures would have been studied also.

A look at the economic side of a statistically-planned test is worthwhile.

With a well-thought out plan, it is logical to assume that testing will be at a minimum to meet the requirement in contrast to what is often "a long series of overlapping, inconclusive meanderings." Also, there is economy in the fact that the statistically-planned test with the same number of runs, provided definite answers as compared to indecisive ones by the one-factor-at-a-time scheme. It has been shown how the eight observations were used in a number of different ways to furnish sets of totals. This reworking is most economic by furnishing additional hidden replications.

But, it is possible, in some cases, to effect even greater savings by reducing the amount of testing through restrictions or controls, as mentioned earlier. The basis for this type of planning will be the initial background information furnished at the first stage of the program. Thus, on the assumption of no interaction present, and using certain restrictions or controls, the desired information can be obtained with only a fraction of the observations required for even one complete run of all combinations. Often computed interaction effects when not significant may serve as an estimate of experimental error so that only one complete replicate is required. Savings of this sort can be greatly multiplied. There are many formal statistical plans available today to cover a variety of situations.

By no means the least advantage to be derived from statistical planning, is the fact that it requires the investigator to completely think his problem through before starting the test work. This is invaluable.

Statistical planning differs chiefly from the one-factor-at-a-time scheme in that:

(a) Instead of studying the factors

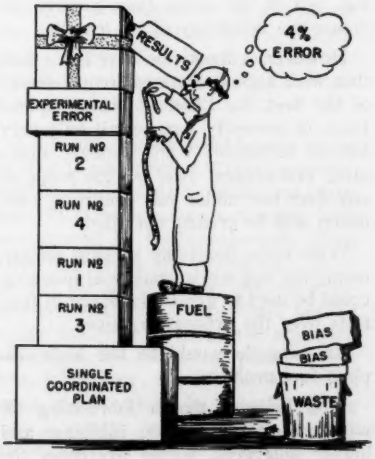

FIG. 7—Results With Statistical Planning.

piecemeal, one-at-a-time, they are all contained within a single coordinated plan. In fact, this consideration of all pertinent factors simultaneously is the distinguishing characteristic of statistical planning.

(b) Randomization is used to insure against bias in results.

(c) Using certain well-defined restrictions (or controls), the amount of testing is reduced, but the reliability is increased.

APPLICATIONS OF STATISTICAL PLANNING

While statistical planning is a necessary adjunct to effective laboratory experimentation, it also pays off in a big way in fleet tests. This is true for two reasons. A fleet test is so very final—second chances are hard to come by. Therefore, there should be careful and meticulous planning down to the most minute detail before launching it. Also, it will be agreed that the uncontrollable factors which cause results to vary are particularly active in fleet testing. They are many times multiplied in the fleet over what would be expected in the laboratory. The greater the inherent variation to be expected in a test program, the more urgent is the necessity for using statistical planning. As enunciated earlier, controls can often be introduced which make it possible to considerably reduce the amount of testing and at the same time greatly increase the reliability of the results.

However, a limitation here is the fact that with high operational requirements of the fleet, the Chief of Naval Operations, of necessity, can permit only very limited deviations from standard operating procedures. And so, the scope of any fleet test under full operating condition will be greatly curtailed.

With some flexibility of ship assignments for test work, statistical planning could be used to great advantage in fleet tests over the present practices.

An example would be the high sulphur fuel problem.

It is believed that a lubricating oil with a better corrosion inhibitor and higher detergent, would overcome the increased corrosion, wear, ring sticking and dirty engines caused by high sulphur content. An in-service testing appears to be required.

It is felt by the lubricating engineers that this problem is sufficiently important to be attacked on a broad scale, giving consideration to the pertinent factors in addition to the lubricant. However, because of the present high operational requirements of the submarine fleet, the Chief of Naval Operations is forced to permit only a very limited use of submarine engines for such a study. A difference in the lubricating oil only is allowed. It has been agreed therefore that eight of sixteen submarines will use standard lubricating oil, and eight the experimental oil, the fuel for all being of the same sulphur content. It is required that the observations of effects be limited to such times as the crafts are available and require no additional work or changes in the standard operation. The necessity for these limitations under present conditions is, of course, understood and appreciated.

With some degree of flexibility, it is agreed a test could be planned with no more than one-fourth as many submarines as presently to be used. Such a plan would provide considerably more reliable information on the two lubricants in question, which is all that can possibly be gained from the present plan, plus information on three other pertinent factors. And, what is equally important, interaction or joint effects of the four factors under consideration. The details of this will, of necessity, be omitted here.

A small list of a variety of examples of successful uses of statistical planning were given in Figure 2. Purposely, these were selected to include those of a nature to be found in Naval laboratories. Three were fleet tests. In fact, a majority of them were Bureau of Ships' problems handled during the War years when there was a strong, active group doing statistical planning.

There will be space to briefly summarize on only one, the first on the list. "Piston ring wear on the main engines used by the CVE 55 class." These engines were of larger design than had previously been used. The design of numerous details had been extrapolated from the smaller designs. Serious piston ring wear in service had been reported. The Statistician set up a plan of study:

5 positions on each ring, the positions of 6 rings on each piston,

5 piston positions on each engine,

2 engines on each ship, and several sample ships were identified.

Ship to ship variation was most important.

Other factors were not.

A statistical analysis indicated a positive correlation between speed and ring wear.

Increased oil dilution at high speeds was most important—more so than length of run. New rules for lubricating rates were formulated and the problem closed.

CLOSING STATEMENTS

It has been shown that the process of statistical planning involves little or no extra expense. The gains are two-fold, (1) what in effect amounts to a more refined instrumentation and (2) in most cases tremendous savings in the amount of testing required. It is the kind of "equipment" which all technical departments can use.

It may be asked as to what extent the statistical planning of tests is being "bought" in research and development programs (Fig. 2). Many industrial and governmental laboratories have added this service, indeed, the line is forming pretty rapidly to the right. Also many quality control engineers are applying these methods to search out causes for out-of-control conditions. It can be stated with confidence that the pioneer stage is well past. That existed some five or ten years ago, so it is evident how rapidly these techniques have caught on with the engineers, chemists, and physicists everywhere.

It is appreciated that every laboratory or organization has its own particular types of problems. Statistical planning to be realistic must fit the practical physical limitations involved. This means that the statistician must work closely with the investigator and become familiar with all phases of the test setup. He cannot work in a vacuum. There must be complete cooperation and confidence with a free exchange of ideas. This does not mean that he will in any way usurp the position of the investigator. His is a technical service and as such he acts as a specialized assistant or advisor on the project.

While the author would want to be the first to admit that not every research problem lends itself to statistical treatment, in many cases opportunities have been missed by the uninformed. How often one hears the statement, "It is fine for the other fellow, but my problems are different." It would neither be fair nor wise to judge the appropriateness of the statistical planning for your laboratory on the basis of this paper alone. Only by actually going over a major test program with a statistician can this be adequately answered.

ACKNOWLEDGMENT

Acknowledgment is made to H. V. Nutt, Superintendent of Fuels and Lubricants Project, and his staff for the refinement of the illustrative material in this paper.

It would be impossible to name all others at EES and at the Bureau of Ships who helped in the preparation of it. Such help is greatly appreciated by the author.

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TECHNICAL PROGRESS IN SHIPBUILDING DURING 1952

ACKNOWLEDGMENT

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In reviewing the progress made in shipbuilding during another year, it is pleasing to be able to state that the industry is still in a fairly flourishing condition, although the shortage of materials, particularly steel, is felt to be slowing down the production of new ships. On studying the figures published by Lloyd's Register of Shipping, one sees that Great Britain still held first place among the shipbuilding countries, the figures for the quarter ended 30th September, 1952, revealing that 343 ships of 2,062,482 tons gross, were under construction at that date in this country. The recovery of the shipbuilding industry in former enemy countries is of interest, and it may be noted that, for the quarter referred to, Japan occupied second place as shipbuilders, while Germany came fourth.

The building of oil-tank vessels represents an appreciable proportion of the work at present in progress, the principal countries in which such ships are under construction being Great Britain, the United States of America and Japan. Oil-tankers in Great Britain represent the largest single class of ship under construction, the next largest being the cargo-liner class.

Of all the ships constructed throughout the world during the past year, perhaps most interest has been shown in the United States Lines' steamship *United States*. This fine vessel, which entered service in July last, has, as is well known, won for the United States the Blue Riband of the North Atlantic. Although the majority of the features of the vessel must, for a long time, remain secret because of the military nature of the design, there is a good deal in connection with her design and construction which is of interest and which may be mentioned.

There is no doubt that the interval of time between the construction of the *United States* and earlier large liners has enabled the use of much more modern machinery, of light weight, which has permitted the production of the power required to give the ship her high speed. The use of light-weight machinery has, in turn, been made possible by the reduction of top-weight in the vessel; and a major factor contributing to this reduction has been the employment of aluminum alloys on a hitherto unheard of scale in the superstructure of the ship. This has also contributed to the reduction in beam which has been

possible, and the breadth of 101 ft. 6 in. is amazingly small as against 118 ft. for comparable British ships. In all, about 2000 tons of aluminum alloy was incorporated in the design of the *United States,* about 1000 tons being employed in the structure and the remainder in fittings and furniture.

Other features of interest in the ship are the absence of expansion joints in the superstructure, the use of welding in the steel structure, and the adoption of high-tensile steel in part of the structure. It is also worth noting that there is no wood in the *United States,* and that the ship is completely fire-proofed; no sprinkler system for fire-extinguishing is provided, as is the normal practice in this country.

Research work on shipbuilding matters has continued during the past year; and while this will be considered in more detail in later sections of the present article, it is fiting to give an outline of work which has been carried on in 1952.

The British Shipbuilding Research Association have, during the past year, expanded their research facilities, particularly at Glengarnock. It will be remembered that work has been proceeding at the testing establishment at Glengarnock for more than 12 years, and the results of these researches given before various technical societies. The facilities, which have proved of immense practical value in the past, have now been improved by the introduction of a new testing machine, capable of applying end loads to structural specimens, in addition to lateral loads. Thus, it is now possible to apply an end load of 600 tons, as well as a lateral load of 300 tons. It is clear that the putting into operation of such a machine opens up a very much wider field of structural research than was possible with the older machine, and one immediately thinks of bottom longitudinals in tank vessels, whose strength might be investigated with this new apparatus.

The British Shipbuilding Research Association are also carrying out investigations on the launching of ships, and this has consisted in model experiments to determine trigger loads, tests on greases and measurement taken at actual launches. The object is to compare the properties of Tallene with those of mineral launching greases.

Another piece of work completed during the past year is the extension of the laboratory and workshop of the British Shipbuilding Research Association at Palmers Hill, Sunderland. This establishment is used for the development of apparatus for use on trials, including that required in connection with vibration work. It is also to be used for a program of structural research on celluloid models, with a view to subsequent investigations on board ship.

Close cooperation between the British Shipbuilding Research Association and the Ship Division of the National Physical Laboratory has continued during the past year, and a large program of loaded measured-mile trials has been carried out by the staff. This has been made possible by the large number of oil-tank vessels under construction at the present time. The National Physical Laboratory are testing models of the ships for which the full-scale performance characteristics have been obtained, and it is hoped, in this way, to obtain a fund of data from which it is expected that more reliable prediction of ships' performance from model tests will be achieved.

A recent addition to the research facilities in the Department of Naval Architecture at King's College (Durham University), Newcastle-on-Tyne, is the towing tank, which was officially opened by the Rt. Hon. the Viscount Runciman of Doxford, O.B.E., A.F.C., D.C.L., President of the Institution of Naval Architects, about the middle of the year. In this tank, which is 130 ft. in length by 12 ft. in breadth, and has a depth of water of 5 ft. 6 in., it will

be possible to tow models up to 7 ft. in length. It is expected that a considerable amount of fundamental research work on hydrodynamic problems will be carried out in the future.

The cavitation tunnel at King's College, which also forms part of the research facilities available in the Department of Naval Architecture, has now been in operation some time, and a considerable amount of experimental work has been carried out. Work on systematic series of propellers of both Admiralty and merchant ship types has been commenced. Theoretical investigations in connection with propellers have also been pursued.

The Aluminum Development Association has continued, during the past 12 months, to show interest in marine matters; and, in addition to the large program of general structural work which they have in hand (some of which will be very valuable from the shipbuilding point of view), a program of research directed particularly to shipbuilding problems in aluminum is in train. Not least among the problems in this category is the application of welding to aluminum, and considerable progress has been made with shielded-arc process. Then, again, attention has been paid to the large riveting question. Various shipbuilding problems are being investigated at Bristol University and at King's College, Newcastle-on-Tyne. In addition, a very extensive program of research on the fireproofing of aluminum structures in ships has been completed during 1952, and this will be considered in some detail in a later section of the present article.

DESIGN AND CONSTRUCTION OF SHIPS

Some very interesting views on the future of merchantship design are to be found in a paper, entitled "Merchantship Design—a Thought for the Future," read by Sir Wilfrid Ayre before the Institution of Naval Architects in the spring of 1952. Sir Wilfrid believes that sound developments in the design of merchant ships of the future are not likely to be affected to any extent by the dictates of fashion, and he considers that progress will rather be the result of an alteration of economic standards and sociological changes.

The author of this paper covers a very wide range of topics, and it is of interest to direct attention to one or two important aspects of the design of ships dealt with. The loss of bulk-carrying, brought about by the disappearance to a large extent of the British coal-export trade, is believed to have been responsible for the greatly increased demand for oil-tank vessels, and has caused tramp-ship operators to look to general-cargo trade and liner services for employment of their existing ships and those which are under contemplation. It is believed that the type of cargo ship having accommodation for 12 passengers will continue in the future.

The general trend towards higher sea speeds in merchant ships is not expected to diminish, and it is predicted that speeds of cargo liners up to 20 knots are likely in the future. In this respect, competition from air transport may well be a large factor in increasing the speed of merchant ships. The question of speed of turn-around of cargo ships, in fact, is an important factor in the economics of a ship, and closely linked to this matter is the question of cargo-handling appliances. It is the belief of Sir Wilfrid Ayre that there is much scope for the designer in producing improvements on the ordinary system of handling cargo by means of winches and derricks. The tendency towards higher sea speeds, it is suggested, requires an effort to be made to use lighter machinery, so that less of the

available displacement is sacrificed to the power, and multiple Diesel engines are considered as a possible solution to the problem.

The location of the machinery in the merchant ship is also an important factor, and it is thought that this should be aft, rather than amidships, thus providing unobstructed cargo space in the main part of the vessel.

While welding is used to a considerable extent at present in shipbuilding, it is believed that the future will see greater use of this method of making connections, and this, in turn, will have a great impact on shipyard layout.

The use of new materials, such as aluminum alloys, with their light weight and higher corrosion resistance, it is considered, will become an important feature of the ship of the future.

Some interesting comments on Britain's liner trade are to be found in a paper entitled "Britain's Deep-sea Liner Trade, 1945-1951, and Some Random Thoughts," and read by Mr. Basil Sanderson, M.C., at the 1952 spring meetings of the Institution of Naval Architects. The losses in the liner fleet sustained during the Second World War have now almost been made good so far as tonnage is concerned, the comparable figures being 8.8 million tons in 1939 and 8.5 million tons in 1951. While this has solved the problem of the number of ships lost during the last war, the problem at present facing the owners of this class of ship is that of replacing obsolete vessels, and this is apparently entirely a matter of economics, as the cost of building tonnage is, at present, excessively high and shows no indication of reduction.

With regard to the future of the cargo liner, it is Mr. Sanderson's view that competition from the air, far from reducing travel by sea, is likely to increase it, due to the fact that this comparatively new means of transport stimulates interest in travel generally, and thereby benefits all concerned.

Technical aspects of the liner type, which should receive attention in the future, concern cargo-handling (with the possibility of radical alterations in design to improve the turn-round of ships), more efficient design of insulation in refrigerated-cargo ships, and the design of hull form.

Useful information on the performance of post-war designed fast cargo liners has been given by Mr. W. H. Dickie in a paper entitled "High-powered Single-screw Cargo Liners," read at a joint meeting of the Institution of Naval Architects and Institute of Marine Engineers. These ships, which were designed in the early part of 1945, were single-screw vessels and were part of an extensive building program. They were in the neighborhood of 480 ft. in length, of some 11,000 tons deadweight, and were propelled by a single screw, driven by double-reduction geared turbines of comparatively high power. The maximum service speed was about 18½ knots, and the machinery had an available power of 15,000 S.H.P. The propellers for these ships were 20.5 ft. in diameter. Very complete data have been made available in this paper regarding the general arrangement, hull form and resistance and propulsion characteristics of these ships.

An interesting survey has been made by Mr. D. W. Low, O.B.E., of the design and development of a special type of craft, in his paper on "Considering Dredging Craft," read before the Institution of Engineers and Shipbuilders in Scotland. These craft have a very important function to perform in keeping the waterways open to the ocean and sea-going craft, and it is not generally understood that a considerable amount of ingenuity and thought has gone into the design and development of these special-type vessels. The progress made in the design of these craft over the past 50 years is very well dealt with

in this paper, which covers many different types of dredgers, including multi-bucket, grab bucket, dipper and suction types.

There may also be quoted two other papers on matters relating to the design, or, at least, to the equipment of ships; these are "Moisture Damage to Cargoes," read by Mr. W. McClimont, B.Sc., before the North-East Coast Institution of Engineers and Shipbuilders, and "Prediction of Thermal Conditions in H.M. Ships in Tropical Waters," by Mr. J. A. B. Gray, M.A., M.B., B.Chir., and Mr. F. E. Smith, before the Institution of Naval Architects.

The former of these papers concerns a subject upon which an increasing amount has been written in recent years, and which has aroused considerable interest. Cargo damaged by moisture does not represent a very large amount when considered as a percentage of the total amount of cargo carried, but, nevertheless, many owners are interested in the matter of preventing such damage as does exist, and it is probable that the future will see more use of mechanical systems of ventilation and drying. Mr. McClimont's paper gives some very useful data regarding the properties of a number of representative commodities of a hygroscopic nature, with particular reference to the requirements necessary for efficient sea carriage.

The subject of the second of these two papers is no less important, as the maintenance of the spaces in warships at the correct temperature is an important factor in the efficient working of the vessels. The high air temperatures and humidities in H.M. ships during the Second World War resulted in the upper permissible limits of the thermal environment being defined. A satisfactory method has been developed for predicting, before a ship leaves home waters, the thermal conditions which are to be expected within a compartment under tropical conditions. The difference between the total heat content of the air within a compartment and that of the external air (called the heat gain) is independent of the temperature and humidity of the outside air, provided the ventilation is unchanged. The wet-bulb temperature of a compartment can be predicted by adding heat gain to a given external total heat content, and converting the answer to wet-bulb temperature. For mess-decks, a technique has been used for converting the predicted wet-bulb temperature into effective temperature for air speeds between 20 and 300 ft. per minute.

STRUCTURAL STRENGTH AND WELDING

The past year has seen the publication of the results of a considerable amount of experimental work in connection with the structural strength of ships and the related problem of welding. A further series of results of experiments on the longitudinal bending of ships has been provided by the publication of the paper entitled "Structural Strength Investigations on the Destroyer *Albuera*," read by Mr. D. W. Lang, B.Sc. (Eng.), A.C.G.I., R.C.N.C., and Mr. W. G. Warren, R.C.N.C., before the Institution of Naval Architects in April last.

It is nearly 50 years ago since the Admiralty carried out tests on H.M. destroyer *Wolf*, and for a long time the results of these tests remained the only data in existence. In recent years, however, there have been several other sets of similar experiments, both in this country and abroad, and on merchant and naval vessels. These latter experiments have all benefited by the great strides which have taken place in the methods for making scientific measurements, particularly of strain, in the intervening time. Good examples of these

developments are the electrical resistance gage and the acoustic strain gage.

The *Albuera* had a length B.P. of 355 ft., a breadth extreme of 40.25 ft. and a depth molded of 22 ft., and she was eventually tested to destruction in a dry-dock.

For the first series of tests, the vessel was maintained at a constant waterline by means of water ballast, and various loadings were obtained by moving the water from place to place in the ship. For the final test to destruction, the ship was supported by two transverse girders, which passed through the hull near amidships. These girders were each supported on two towers, which stood on the dock bottom. The ship was also partially supported by water in the dock, and loading was applied by means of water ballast. The types of strain gages used in the experiments were acoustic gages, electrical resistance gages, and long-base strain gages, measuring strains over lengths of 13½, 15 and 100 in. Deflections were measured by means of a theodolite.

The analysis of the results of these experiments showed that, with reasonable accuracy, the ordinary theory of bending would forecast the stress in the structure. The experiments did, however, indicate that the stress at the deck edge was higher than at the center, and that modifications to ordinary beam theory, to take into account shear stresses in the structure, would account for this qualitatively, but would not account for the whole difference between theory and experiment. It was considered that the proximity of the test section to the break of the forecastle had some influence on the stress distribution.

When loaded to destruction, the vessel was in the hogging condition, and the first sign of failure was the wrinkling of the ship's side plating just abaft the after support. Collapse finally took place by the buckling of the bottom and side plating, and there was also transverse deformation of the side framing.

In commenting on this work, it can be said that the results of the experiments give some very useful information on the behavior of full-scale structures under load. Taken in conjunction with earlier work on both merchant and naval vessels, a very complete picture is obtained, and it is very satisfactory to realize that ordinary beam theory, which was developed for a very simple type of loading, can be applied with reasonable success to the complicated structure of a ship when subjected to an equally complicated distribution of loading. Thus, broadly speaking, confirmation has been obtained of the fact that designing on the basis of beam theory will lead to satisfactory structures. It is unlikely that we shall see, in the future, another series of experiments of this nature.

Less spectacular perhaps, but nevertheless just as important as full-scale experiments on strength of ships, are tests on structural components. The British Shipbuilding Research Association has made available during the past year a further series of tests carried out at Glengarnock on what is now called the No. 1 testing machine. The results of these tests have been recorded in a paper, "Ship Structural Members—Part V," read by Mr. A. G. Hadjispyrou and Mr. H. Lackenby, M.Sc., before the Institution of Engineers and Shipbuilders in Scotland. This represents the fifth instalment on ship structural members, and follows on the work which has already been published in four papers to the various technical societies of the country.

The present work is mainly on welded sections, but a comparison is made between these and riveted channel and bulb-angle sections. The types of welded section tested consist of bulb plate, inverted angle, fabricated tee-bar and a flanged plate. The depths of the specimens tested were 12 in. and 9 in., and the effect of cutting scallops in the webs of the welded stiffeners and slots

in the webs of the riveted stiffeners was investigated.

Points of interest from the tests are that unattached stiffeners give some degree of fixity at their ends, the bending moments at mid-span varying between WL/8.2 and WL/9.5, and that stress at center of span and deflection decrease with increase in bracket size, but the influence of bracket size is much less marked on deep stiffeners than shallow stiffeners. Welding instead of riveting brackets showed a considerable improvement in so far as stress and deflection are concerned. The influence of scallops and slots in the webs was practically negligible in the larger specimens. In the smaller specimens, the effect has been to increase stress and deflection. The improvement from a heat insulation point of view of slotting the webs was investigated, and this was found to be very small indeed, the improvement being only about 0.6 percent with a 12-in. depth of insulation and 2-in. of cork over the face flange.

An interesting review of the longitudinal-strength problem has been made by Mr. James Turnbull, O.B.E., in his paper on "Longitudinal Strength—a Review of Some Recent Developments," discussed at the September meeting of the Institution of Naval Architects. In this paper, recent developments in this all-important subject are reviewed, and some of the conclusions regarding the relative merits of riveted and welded ships are of considerable interest.

The author quoted the results of the *Neverita* and *Newcombia* experiments to show that, in so far as deflection is concerned, there is little or no difference between the two types of construction. Again, these same experiments appear to have repudiated the suggestion that riveted ships are more flexible than welded ships, on account of rivet slip. Efforts to measure this mysterious quantity failed in these full-scale experiments, and it is apparent that, in the most recent tests on the destroyer *Albuera,* slip was not detected.

Generally, the stress distribution in welded ships is very similar, except that there tends to be more unfairness of plating in welded ships, leading to differences in the heart-of-plate stress. Stress concentration factors in ships around hatch corners may be of the order of 2.5, and these, in general, tend to be greater in welded than in riveted ships.

An important piece of information which has come out of the sea trials of the *Ocean Vulcan* concerns the number of reversals of stress and the magnitude of the reversals which a ship is subjected to over a given period. This, obviously, has a bearing on the fatigue strength of the structure.

The following figures, quoted from Mr. Turnbull's paper, and which were taken over a period of one year, are of considerable interest:—

Range of Stress, tons/sq. in.	Number of Times Experienced.
1	266,884
2	7,105
3	1,329
4	102
5	5
6	2

While it is possible that much more severe conditions than this might be experienced, it is clear that, in general, the number of times that a ship is subjected to a very high stress range is very small. Fatigue may not, therefore, be important from the point of view of the general longitudinal strength of the ship, but may, nevertheless, become important where there are stress concentrations, such as at hatch corners.

Research work on ship structures has continued in the United States during the past year, under the Ship Structure Committee, formed in 1946 with the object of initiating, sponsoring and interpreting research work bearing on im-

provements in ship structures. The Committee represents both merchant-ship and Navy interests. One of the major concerns of the Ship Structure Committee is to study the strength of welded ships, since it was largely due to failures in some such ships that led to the formation of the Committee.

Useful information on the work of the Committee is to be found in a paper entitled "Research under the Ship Structure Committee," read at the November meeting of the American Society of Naval Architects and Marine Engineers by Captain E. A. Wright, U.S.N., Mr. Finn Jonassen and Mr. H. G. Acker. Some of the conclusions in this paper are of interest. The good behavior of ships built since the end of the Second World War has been the result of improvements in design, steel and fabrication, all of which have been aided by the research program of the Committee. The use of crack arresters in structures has been effective, although there are cases where ships fitted with such arresters have fractured.

An interesting and important finding is that full-scale models of structural components are not so strong in terms of nominal stress as the corresponding strength of reduced-scale structural models. The extended use of non-destructive sub-surface methods of inspection are recommended. A large proportion of the research program sponsored by the Ship Structure Committee will continue to be aimed at the solution of the crack problem; and once this problem has been solved, it is expected that the research activity of the Committee will be directed towards improving the general structural effectiveness of the ship's hull, and in reducing building and operating costs.

With regard to welded-ship construction, its influence on yard design and layout is well-illustrated by the reorganization of the yard of Messrs. William Doxford and Sons, Ltd., Sunderland. This matter was dealt with by Mr. C. Stephenson in a paper which he read before the North-Eastern (Tyneside) Branch of the Institute of Welding. The early use of welding in ship construction some 20 years ago was a direct substitution for riveting, the method of erection being very much the same as in a riveted ship. The advantages of prefabrication became evident, however; and, with the advent of the Second World War, this was practiced to a great extent, and has since been used whenever possible in the construction of all-welded ships.

One major effect of prefabrication is that the time which the ship is on the building berth is greatly reduced; so that (for a given steel tonnage output), in a shipyard originally based on the idea of fabricating the ship on the berth, some of the berths become redundant when large-scale welding is adopted.

To quote the case of Messrs. Doxford, the output of six berths under the existing scheme could be maintained with only three berths and slightly reduced man-power, if large-scale prefabrication were introduced. This plan has been followed by Messrs. Doxford, and three of the existing berths, together with the area covered by the scrieve boards, platers' shop, furnaces, beam machines, etc., were scheduled for re-development. Three prefabricating shops were erected, with the open ends facing the tops of the berths.

It is of interest to quote some of the output figures given by Mr. Stephenson in his paper. The first vessel constructed under the new conditions was an oil-tank ship of 16,750 tons deadweight, involving the use of 4100 tons of steel plates and sections. Work on the ship was commenced 17 weeks prior to the laying of the keel, and, at the time of the keel-laying, 51 percent of the material had been prefabricated. From keel-laying until launching occupied 22½ weeks.

The reconstruction in Messrs. Doxford's shipyard is indicative of the changes which are being brought about by the introduction of the all-welded ship, and show that shipbuilders are alive to changing conditions, and have, in many cases, shown great ingenuity in adapting limited space to meet the progress of the times. It is evident that, despite failures of all-welded ships which are reported in some countries, we shall, in the future, see more and more of this type of construction. The size of the all-welded ship is continually increasing, as is evidenced by the fact that some of the largest oil-tank vessels under construction at present are being welded.

Another paper of extreme interest in regard to the subject of reorganization of shipyards for welding is that read by Mr. J. Rannie, of Messrs. John Brown & Co., Ltd., before the Glasgow Section of the Institute of Welding. In this paper, Mr. Rannie describes the changes which have taken place in recent years in this famous Clydeside shipyard.

Some interesting information on the brittle fracture of steel has been made available during the past year by the British Welding Research Association; and while these results are of very wide general application, they are obviously of great importance to shipbuilding. The report relates to tests made to ascertain the influence of residual stress on the brittle fracture of steel. Butt welds were made in material ¾ in. thick, which was under very severe conditions of restraint.

The steels used were ordinary coarse-grained mild steel, with a high Izod transition temperature, a normalized low-carbon, open-hearth, aluminum-killed fine-grained steel with a low Izod transition temperature, and a normalized weldable, high-tensile chromium-molybdenum steel of fine-grain size and low Izod transition temperature.

The conclusions are of very great interest. There was no indication in the tests that residual stresses introduced due to welding would make a material liable to brittle failure at higher temperatures than those at which brittle failure might be expected to occur in the absence of residual stress. Residual stress of sufficient severity may produce brittle fracture of welded assemblies without additional external stresses, but only if severe notches are present, and if the temperature is below the lowest value at which a severely notched tensile test-piece would break in a ductile manner, or at which the Izod impact strength would still be reasonably high. There was no indication that brittle fracture would occur while the structure was at a temperature above the Izod transition range of the material, even in the presence of severe notches and complex states of residual stress.

The work covered by the report mentioned in the foregoing is of an exploratory nature only, and it is expected that this very important research will continue and that further information will be released in the future.

Two subjects of interest upon which papers have been written during the past year are rudder failures and the reinforcement of holes. Mr. T. W. Bunyan, B.Sc., has dealt with the former of these problems in his paper, "A Study of the Cause of some Rudder Failures," before the North-East Coast Institution of Engineers and Shipbuilders. It appears that vibration of the rudder of a ship is a likely occurrence in certain circumstances, and that such vibration will account for the wear and tear of certain rudders and their attachment to the hull. Tests have been carried out using a vibration exciter, and these have established the existence of rudder critical frequencies, and the forces generated are sufficient to cause appreciable hull vibration. The tests indicate that it is possible to calculate the various critical frequencies of vibration of the rudder with reasonable accuracy. The results put forward by Mr. Bunyan in his paper

form a most interesting introduction to what would appear to be a hitherto neglected subject.

The second subject referred to in the preceding paragraph, *viz.*, the reinforcement of holes, has been discussed by Lieut.-Commander S. R. Heller, Jr., U.S.N., in his paper entitled "Reinforced Circular Holes in Bending with Shear," read before the American Society of Naval Architects and Marine Engineers in November last. A family of specimens was tested in bending with shear, in which circular holes up to half the depth of the web were made. Reinforcement up to twice the area of the hole was originally used, and this was progressively reduced. Strain was explored by electrical resistance strain gages. The results showed that any reinforcement reduces the stress level at the edge of the hole, but that after a certain amount (usually about the same area as the hole), additional reinforcement is of little effect.

Interest continues to be shown in the application of aluminum alloys to ships, and reference has already been made to the *United States* in this respect. Several Continental-built passenger ships have employed aluminum in their deckhouse structures, and this is becoming quite an accepted method of utilizing the material. Applications to such items as lifeboats continue to be made, of course. An interesting use of aluminum in this country has been in barges for the Belgian Congo. Messrs. Thorpe Brothers (Bessborough Works), Ltd., of West Molesey, Surrey, have constructed 60 of these craft, each of which is 77 ft. by 11 ft. 6 in. by 4 ft. 6 in. The cubic capacity of these barges is 2640 cu. ft., giving a carrying capacity of 66 tons at 40 cu. ft. per ton. The plating of the sides, deck and bottom consists of NP5/6 material, which is a non-heat treatable alloy, the thickness being $\frac{3}{16}$ in. The sections are extrusions in the heat-treatable HE10 alloy. A careful study of the problems of construction and prefabrication has led to appreciable reductions in the cost of construction—an important matter when dealing with a material which is more expensive than steel.

Another extremely interesting application of aluminum for ship construction is in the twin-screw motor yacht *Tonquin*, built by Messrs. Grimston Astor, Ltd., of Bideford. The craft has a displacement of 14 tons, is 60 ft. in length by 14 ft. 9 in. in breadth, and has a draft of 2 ft. 9 in. The hull, which is all-aluminum, is constructed on the two-way tension system, in which the sheets forming the shell are first of all fastened together in the flat state, after which the frames, bent to the correct shape, are attached to the center of the sheets. The sheets are then drawn up to the transverse members.

Yet another example of the progress made in this field is in the application of aluminum to the superstructure of the Thames motor launch *Queen Elizabeth*. The point of interest in this particular superstructure is that the aluminum sheet has been welded by the consumable-electrode process, commonly known in the United States of America as the Aircomatic process. This is probably the first application of the process, to shipbuilding, in the British Isles, and no doubt the future will see a much more extensive use of the method in this field.

An informative survey of the position with regard to aluminum in shipbuilding generally has been given by Mr. E. C. B. Corlett, M.A., Ph.D., in his paper, "Aluminum as a Shipbuilding Material," before the North-East Coast Institution of Engineers and Shipbuilders. A wide range of topics is covered, including the choice of material for plates and sections, and the development of new structural sections, and he gives recommendations for the scantlings of deckhouses, etc. It is of interest to note that the choice of material now lies be-

tween the aluminum magnesium alloys, with about 3.5 to 5 percent Mg., and the heat-treatable aluminum-magnesium silicide alloy. There is a tendency, nowadays, towards a material containing just over 4 percent magnesium, as this is easier to manufacture than materials with a higher magnesium content. With this amount of magnesium, it is possible to meet the requirements of Lloyd's Register of Shipping in regard to the minimum properties for aluminum alloys. A useful structural code of design is given in this paper, which should be exceedingly helpful to designers.

Finally, in connection with aluminum construction, Mr. W. Muckle, M.Sc., has contributed to the Institution of Naval Architects a very interesting paper on "The Scantlings of Long Deckhouses Constructed of Aluminum Alloy." The paper gives a comparison between aluminum and steel houses based on the scantlings which Lloyd's Register of Shipping now require in steel construction. It is of interest to note that, in one-tier and two-tier superstructures, the decks covering the houses could be of lighter scantlings, than required in a steel structure if only ordinary longitudinal-strength considerations are being taken into account. It appears, however, that the thickness might need to be increased to resist buckling unless special precautions are taken to deal with this matter. A good working rule, then, is that the cross-sectional area of superstructure decks should be the same in aluminum alloy as in steel with certain limiting thicknesses, in order to produce adequate resistance to buckling. According to Mr. Muckle's paper, if this is done, weight ratios of between 40 and 45 percent are obtained, which means that about 55 to 60 percent of the weight of a steel structure can be saved if aluminum alloys are used.

RESISTANCE AND PROPULSION

The frictional resistance of ships is a problem which has been studied for very many years, the first systematic investigation being that of Froude in the second-half of the last century. It would be untrue to say that the problem has been solved, in spite of the advances which have been made since Froude's day. We have seen, in recent years, a departure from the Froude empirical type of formula and the introduction of formulae cast in a more fundamentally correct form in terms of Reynolds number. A typical example of this type of formula is that due to Schoenherr; and, at the time of the publication of his paper in 1932, the summary and collation of existing data on skin-friction resistance which he gave were of great value.

It should be noted, however, that, despite the very wide adoption of the Schoenherr line, especially in the United States, it is still found necessary to add empirical values to the resistance coefficient so determined, in order to give a fair estimate of frictional resistance for a ship. Additional data on this all-important subject are, therefore, welcome; and these have been provided by the publication of details of new work on frictional resistance carried out by the National Physical Laboratory, and included in the paper entitled "Frictional Resistance of Smooth Plane Surfaces in Turbulent Flow—New Data and a Survey of Existing Data," read by Mr. G. Hughes, D.Sc., Ph.D., before the Institution of Naval Architects at the 1952 spring meetings.

The tests made were of two types. In the first series, planes were towed vertically and had freeboard; that is to say, the upper edges projected above the surface of the water. The second series of experiments was on flat-bot-

tomed shallow-draft pontoons, not unlike those tested many years ago by Kempf. Various surfaces were used, including wood, metal and glass. The planes were from 2 ft. to 15 ft. in length, while the lengths of the pontoons went up to 60 ft. A special dynamometer was devised for use in these experiments, and this was sensitive to very small loads. The results of the experiments are shown to conform to a consistent picture when account is taken of the length/breadth ratio of the planes. There is, however, no single friction line to a base of Reynolds number which will represent the results, but a family of lines varying with the length/breadth ratio. A line for zero value of this ratio has been approximately established for Reynolds numbers from 100 thousand to 10 million. The line is generally lower than other proposed lines. An upper line corresponding to a large value of the length/breadth ratio is also proposed over a range of Reynolds numbers from one million to 100 million, and this line is considerably higher than the line for length/breadth ratio = 0 by an approximately constant ratio in the overlapping range for Reynolds numbers from one to 10 million. No formula has been proposed, as yet, for these lines, and it is hoped to carry out check tests, and to extend the range of Reynolds numbers, before final proposals are made.

Professor E. V. Teller, D.Sc., Ph.D., has continued his work on his own particular method of dealing with the problem of extrapolating model resistance to the full-size ship. His latest contribution to this field of investigation is to be found in his paper entitled "Ship-model Correlation," read at the 1952 autumn meetings of the Institution of Naval Architects. Professor Telfer states that this problem of ship-model correlations has caused considerable anxiety to shipbuilders. He also remarks that the introduction of the fully-turbulent model has coincided with the smooth hull of the welded ship and the increasing preference for Diesel propulsion, with the use of the low pitch-ratio screw, resulting in favorable scale effect. Consequently, larger propulsive coefficients are being obtained than would be expected from model experiments. Professor Telfer deals successively with the correlation of resistance between model and ship, determination of ship thrust deduction, and the propulsive coefficient and shaft horse-power correlation.

The prediction of ship power from model experiments was the subject of a paper read by Mr. J. L. Kent, C.B.E., before the North-East Coast Institution of Engineers and Shipbuilders at the beginning of 1952. The method adopted by R. E. Froude and Dr. G. S. Baker was to obtain the ratio Effective Horsepower/Delivered Horsepower from the model when it was just self-propelled, and to assume that this propulsive coefficient was the same for the full-sized ship at the corresponding speed. An alternative method to this is to calculate the propulsive coefficient at the apparent slip at which the model is under-propelled by the amount of the skin-friction correction, and to use this coefficient in calculating the ship horsepower.

Neither of these methods has given really satisfactory results, and Mr. Kent proposes a new method for dealing with the problem. He suggests treating the model, when propulsion tests are being made, as a ship on trial, without reducing the resistance by a problematic skin-friction correction or attempting to produce artificial hydrodynamic conditions. The torque-slip experiment data obtained from the model should be used to produce the torque-slip data for the ship by an empirical calculation based on known facts. From the data given in the paper, it is apparent that the new method gives a better estimate of ship revolutions, but it is doubtful if the estimates of power are as good. Mr. Kent clearly realizes the need for further in-

vestigation on this matter, and suggests lines for future research. There is no doubt that this paper will stimulate thought on this all-important matter of prediction of ship powers.

The results of a most important new series of propeller experiments have been made available by Mr. R. W. L. Gawn, O.B.E., R.C.N.C., in his paper, "Effect of Pitch and Blade Width on Propeller Performance," read at the 1952 autumn meetings of the Institution of Naval Architects. The experiments were on three-blade propellers and covered a wide range of pitch ratios from 0.4 to 2. The blade-area ratio varied from 0.2 to 1.1. The size of the models is worthy of note, these being 20 in. in diameter and being tested over a range of slip from zero to 100 percent. The blade sections were of the usual segmental shape, and the blade outline was eliptical. The blade-thickness fraction was 0.06, and the boss diameter was 0.2 times the propeller diameter.

The propellers were tested at an immersion of 22 in. to the center of the shaft, and one propeller of the series was tested over a range of immersion from 16 in. to 22 in. For these experiments, a specially designed dynamometer was constructed, the capacity being 18 B.H.P. The standard rate of revolutions for the tests was 500 per minute, and the maximum speed of advance at these revolutions varied from 22 ft. per sec. for the propellers of the largest pitch ratio, to 6 ft. per sec. for the propellers of the smallest pitch ratio.

At the Reynolds numbers at which these model experiments were carried out, it is believed that the propellers were free from laminar flow, the tests having extended to a Reynolds number of 4.3 million. One consequence of this is that the results may be applied to actual full-size propellers, with a relatively small correction for skin friction. The results of the experiments are presented as a series of curves of thrust and torque coefficients and efficiency, each curve being for a constant-pitch ratio. A separate diagram is given for each blade-area ratio.

A point of great interest is the comparison between the present series of experiments and other standard series. There are discrepancies which can be accounted for by differences in design, and probably also by scale effect. This series of experiments, there is little doubt, will prove of great value to propeller designers, especially those concerned with high-powered craft. The size of the models used is a considerable advantage, as compared with earlier series, and this should add to the reliability of the present work.

Theoretical investigations of propeller performance have continued during the past year, and Dr. H. W. Lerbs has contributed a paper on this subject, under the title of "Moderately-loaded Propellers with a Finite Number of Blades and an Arbitrary Distribution of Circulation," to the American Society of Naval Architects and Marine Engineers. Dr. Lerbs has considered the propeller blades to be replaced by lifting lines, the circulation of which depends upon the radial coordinate. Due to the variation in circulation along the blade, a free vortex line is shed from the blade, and the adjacent vortex lines form a vortex sheet. The work in the paper is concerned with the determination of the velocity field, due to these vortex lines, in a non-viscous fluid. The results obtained are plotted for propellers having three, four and five blades. The basic considerations are then applied to free-running optimum propellers with both zero and finite hub diameters. Then the method is applied to the propeller working in a radially varying wake.

The problem of cavitation is of great importance to the naval architect concerned with the design of propellers. It is, however, of equal importance to

engineers in the design of hydraulic equipment. Fundamental researches on such a subject will, therefore, be of interest to all concerned, and the James Clayton Lecture delivered, in April last, before the Institution of Mechanical Engineers should be of considerable value to the naval architect. The lecturer on this occasion was Professor Robert T. Knapp, Ph.D., of the California Institute of Technology, who took as his subject "Cavitation Mechanics and its relation to the Design of Hydraulic Equipment." Professor Knapp described research work on cavitation which has been carried on mainly for the Department of the Navy of the United States.

A feature of particular interest in this work is the use of high-speed photography. For example, pictures at the rate of 20,000 frames per sec., have been taken in studying the growth and the development of a cavitation bubble. A phenomenon which this high-speed photography has revealed is that, when a cavitation bubble is initiated, it grows to its maximum size, collapses, then re-appears, this time as a smaller-diameter bubble. The process is repeated several times, each successive appearance resulting in a bubble of smaller diameter. This is only one of the many extremely interesting topics dealt with by Professor Knapp, and, although the work is not primarily concerned with propellers, it will repay careful study by naval architects, as it obviously has an application to that particular problem.

VIBRATION, OSCILLATION AND MISCELLANEOUS TOPICS

A most interesting contribution, during the past year, has been to the problem of ship vibration by American naval architects. This concerns what has come to be known as "fantail" vibration, and occurs particularly in Great Lakes ore-carriers. These ships, which were formerly powered by engines of about 2000 I.H.P. and had revolutions of about 85 per minute, on the average rarely experienced hull vibrations. With the trend, in recent years, towards higher powers and engine speeds, where the revolutions have crept up to between 100 and 130 per minute, excessive fantail vibration has been experienced.

This problem became very serious in the ore-carrier *Wilfred Sykes*. The vibration in the after end of this vessel was extremely vicious, was accompanied by a considerable amount of noise, and serious damage was experienced. A feature of this type of vibration is that, forward of about one-quarter of the length from the after end, little or no vibration is to be felt.

Such a state of affairs could not exist if the ship were vibrating in one of the many simple flexural modes of vibration, and the conclusion arrived at is that several of the ordinary modes of vibration are excited simultaneously, their net result being that the vibrations eliminate each other in the forward section of the ship, but build up to give a very large amplitude at the after end. Apparently the cause of these vibrations is the propeller, the hydrodynamic forces set up giving the necessary excitation for vibration.

A study has been made, by means of model experiments in a circulating water channel, of the flow in the neighborhood of the propeller. These have shown that there was a down draft in a region starting about 15 ft. to 18 ft. forward of the propeller, and extending down to the shaftline. The water was very disturbed and agitated, and only in the lower half of the propeller disc did there seem to be a solid intake flow. The model experiments were continued

with the addition of horizontal fins in the affected region, and it appeared that these were effective in straightening out the flow of water. The effect on speed and power of the addition of these fins was very slight, and it was decided to embark upon the experiment of fitting these in the *Carl D. Bradley*, one of the affected vessels.

The results of trials at various speeds have shown that the greatest amplitude of vibration does not exceed 0.008 in., whereas, before the fins were fitted, amplitudes many times this value were obtained. It would appear that the method adopted is at least one way of solving a rather difficult problem, without the necessity of fining the after-body lines of the ship, and thus reducing the deadweight-carrying capacity.

A more detailed discussion of this very interesting problem is to be found in the paper entitled "Vibration at the Stern of Single-screw Vessels," read by Mr. L. A. Baier and Mr. J. Ormondroyd before the American Society of Naval Architects and Marine Engineers in May, 1952.

Mr. A. J. Williams, R.C.N.C., has given the results of some experiments on rolling in his paper, "An Investigation into the Motions of Ships at Sea," read before the Institution of Naval Architects in September last. These experiments were carried out on full-sized ships, those principally concerned being H.M. ships *Cygnet* and *Cumberland*. The trials had the practical object of obtaining data for the design of stabilization systems.

It is of interest to quote some of the results of these experiments. Apparently, the rolling of a ship in confused seas tends to be in the still-water period of the ship, that is to say, this period predominates. Heavy rolling approximates to simple harmonic motion, and no great error results from calculating angular velocities and accelerations on this assumption. In contrast to the rolling motion, the period of pitching approximates to the period of encounter of the waves with the ship, but, in general, the motion is distorted by a free oscillation, which is believed to be in the still-water pitching period.

A subject not often dealt with is the acceleration of ships, and Mr. H. Lackenby, M.Sc., has given the results of research carried out by the British Shipbuilding Research Association, in a paper, "On the Acceleration of Ships," read before the Institution of Engineers and Shipbuilders in Scotland in February last. The problem is important in such instances as determining the length of run that a ship should have before coming on to the measured mile.

Generally speaking, if the propelling machinery of a vessel is set to give a certain speed, the propeller delivers a thrust which exceeds the resistance before the ship has achieved this speed, and it is this excess of thrust which causes the vessel to accelerate. As the speed becomes higher, the excess thrust diminishes, until, at the full speed, it is zero. Theoretically, it requires infinite time to reach this condition, but it is possible to calculate the time and the distance run before the speed reaches any desired amount less than the full speed.

In Mr. Lackney's work, the speed is taken as 0.999 of the full speed. Various approximations are made to the curves of thrust of the propeller, based on standard series results, so as to obtain formulae which are easy to apply in practice. It is of interest to note that the high-speed ship requires a relatively shorter run to attain full speed than a slower vessel, and that the effect of moderate initial speed on the length of run required is small. This has been confirmed by the results of other writers on the subject, and also by model experiments.

A problem of great concern to owners of tank vessels is that of corrosion in

the cargo-oil tanks. In this connection, the American Society of Naval Architects and Marine Engineers included in their November meetings a short symposium on this all-important subject. This symposium began by defining the problem, proceeded to consider the effect of inhibitors in the cargo, and then dealt with corrosion control in practice. The use of inhibitors in the cargo appears to be an attractive proposition; and, from the results mentioned, it would seem that the additional cost—which would probably amount to about 14,000 dollars per annum for a T-2 tanker—would be more than offset by the better condition of the tanks, and the reduced quantity of steel replacement required due to the reduction in corrosion.

The fire-protection of ships is an important matter, and the introduction of aluminum into the superstructures of large passenger ships has brought with it problems in this respect. This is because of the lower melting point of aluminum, as compared with steel. In consequence, in the event of a fire, the temperatures may be sufficiently high to cause melting of the material, and thus permit the progress of fire throughout the vessel. In view of this, naval architects interested in aluminum construction will welcome the results of a very complete series of fire tests which were published during the past year by Mr. J. Venus and Mr. E. C. B. Corlett, M.A., Ph.D., in a paper on "Fire-protection in Passenger Ships," before the Institution of Naval Architects.

The tests described in this paper were carried out at the Fire Research Station at Elstree, and were planned in conjunction with the Ministry of Transport. The first tests were made on bulkheads of aluminum alloy, stiffened in the usual way, and protected by various types of insulation. Deck tests were made, and, at a later stage, a complete cabin was tested, the last-mentioned having the usual amount of combustible material which is to be found in such a space. It is not possible to discuss, in this review, all the results of the test, but it is sufficient to mention that the tests showed that aluminum can be adequately protected against fire.

It is considered that, for economic reasons, the best method of fire-protection with aluminum structures is that referred to as Method I, in the International Convention for the Safety of Life at Sea. Matters which need to be given special care are the allowance for expansion when such materials as asbestos board are used for protection, and also the jointing of such boards—especially at corners—needs to be considered very carefully.

In concluding this survey of technical progress in shipbuilding during 1952, attention may be directed to two other problems which received some consideration recently. The first of these is launching, a subject on which Mr. A. Silverleaf, B.Sc., read a paper before the Institution of Engineers and Shipbuilders in Scotland, in February last. The object of this investigation was to simplify launching calculations and to reduce them to a standard form. The author has produced a series of diagrams which enable the usual launching curves to be derived, without going through the full launching calculations.

The second matter mentioned in the preceding paragraph is that of determining keel-block pressure. This has been the subject of a paper ("A New Method for Computing Keel-block Loads") read before the American Society of Naval Architects and Marine Engineers in November last, in which a detailed method is derived for calculating the distribution of the loads along the length of the keel of a ship in a dry-dock. The stresses in the ship are also dealt with, and the method is illustrated by a calculation for the passenger liner *America*.

MEETING FUTURE PETROLEUM DEMANDS

PART I

ACKNOWLEDGMENT

This is an abridged version of a paper presented at the 32nd Annual Meeting of the American Petroleum Institute in Chicago, Illinois, on November 10, 1952. It analyzes the probable availability of crude oil and natural gas liquids during the next 15 years, including the effects of Canadian and Near East developments. Demand is forecast and refinery capacity is estimated. Part I was written by MR. JOHN E. SWEARINGEN, General Manager of Production, Standard Oil Co. (Indiana); Part II was prepared by MR. JOHN W. BOATWRIGHT, General Manager of Distribution Economics, Standard Oil Company (Indiana).

INTRODUCTION

The paper which I present will discuss the future of our oil supply, and will be followed by another to be presented by Mr. John W. Boatwright, general manager of distribution economics for the Standard Oil Company (Indiana) and an esteemed colleague of mine who will discuss demand and other aspects of the over-all picture. These 2 papers will give our forecast of the outlook for supply and demand facing our industry during the next 15 years.

This general subject is one about which much has been said in the past, and much will continue to be said in the future. It is a subject of vital importance to all oil men—not only from the standpoint of their own future planning, but also from the standpoint of government actions which control the whole economic environment in which the industry must operate.

In the face of extensive studies in this field by the President's Materials Policy Commission (the Paley committee), by the National Petroleum Council, and in many other excellent papers, it is a bit venturesome for us to appear before you and claim that we have something new to say. But, as all soothsayers have different incantations and different ingredients for making up a potion, I may say that we have brewed and seasoned this forecast to our own taste. When I have completed my part of the presentation, I shall be glad to try to answer questions on any of the material I have covered, but I hasten to add that I hope you will delay your tough questions and put them to Mr. Boatwright.

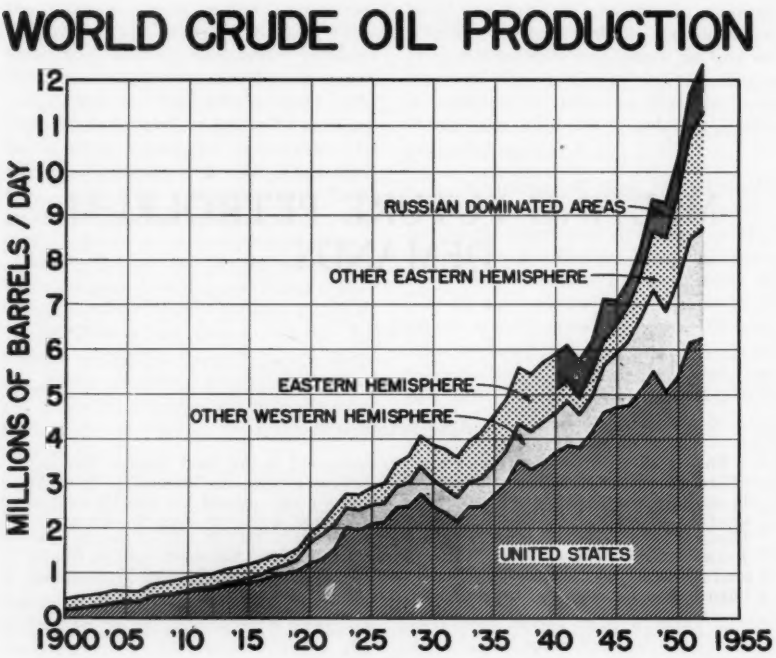

FIGURE 1

Forecasting the future rate of oil discoveries and availability is fraught with many pitfalls and difficulties. Most forecasts of oil availability have been prepared in the classical fashion of deriving trends of significant variables from historical data and projecting these trends into the future. For several years we attempted to do the same thing, but we have now reached the conclusion that inherent uncertainties in the basic statistics are such as to make any forecast based on them unreliable. It is axiomatic in the producing business that there is a great time lag between expenditures for exploration and the payoff in production. On the other hand, certain general relationships appear to exist between exploratory effort, production, and reserves, and these cannot be completely disregarded.

Growth in Production

To provide some background for the problem with which we are dealing, Fig. 1 shows the tremendous growth in U.S. and world crude-oil production over the past half-century.

It can be noted from Fig. 1 that, from almost insignificant beginnings at the turn of the century, the rate of crude-oil production in the United States has grown steadily to more than 6 million 100 thousand barrels per day in 1951. In September of this year the United States produced oil at a rate slightly above 6.5 million barrels per day. The average for the year, of course, will be somewhat less.

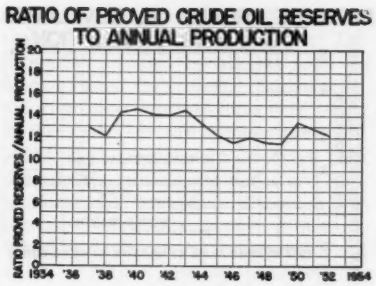

FIGURE 2

World crude-oil production now stands at a little over 12 million barrels per day, with the largest producers of the free world outside the United States being Venezuela and the countries of the Middle East. One fact is evident from Fig. 1. The growth in production of crude oil in the past decade has been much more rapid outside the continental United States than inside the borders of this country. Even a casual observation of Fig. 1 naturally raises the question: "How long can we continue to produce oil at an expanding rate without becoming dangerously dependent on foreign sources of supply?"

U.S. Crude-Oil Reserves

In trying to answer this question, the first thing to examine is the inventory of proved crude-oil reserves standing on the books. During the past 15 years our country has more than doubled its proved reserves of crude oil, and this does not take into account an additional reserve of 4 billion barrels of natural-gas liquids which adds about 15 percent more reserve supply. And this result has been accomplished while we were producing 24 billion barrels of crude oil. Only during the war years has the industry failed to add substantially to its crude-oil reserves. This I attribute principally to lack of steel pipe and skilled manpower during the war to carry on normal activities.

Reserves Vs. Production

Fig. 2 shows the ratio of reserves on January 1 of each year to the annual production in the preceding year. It will be noted that this ratio has varied from a low of about 11.5 in 1949 to a high of about 14.5 in 1940, and currently stands a little above 12. These are the figures which give rise to the claims of many uninformed persons that we are running out of oil; that our present supply will last only another 10, 12, or 14 years. In this connection, there are several things I should like to point out.

In the first place, the reserve figures are proved reserves. Conservative figures on proved area, pay thickness, percentage recovery, etc., are used in making up the estimates. The "probable" or "possible" reserves of new areas may be many times larger than the "proved" reserves, but the "proved" reserves are the ones making up the American Petroleum Institute figures. History has shown that API proved reserves for fields in the year of discovery are generally only 15 to 25 percent of the oil ultimately shown to be present.

In the second place, many wells now producing oil will continue to be producing 50 years or more from now. Even if it were desirable to produce all our oil reserves in a period such as 12 or 13 years, it would be physically impossible to do so.

Third, and most important, any such contention completely overlooks the fact that we are finding more oil every year than we are using, and there is every reason to believe that we shall continue to do so.

Proved Oil Developed Vs. Annual Production

It is more logical to look at our proved crude-oil reserves in the manner shown in Fig. 3. Here we have plotted the ratio of proved crude oil developed each year to the then current rate of

production. Fig. 3 shows that every year since 1937, with the exception of 1943, we have developed new oil at least equal to our production. Except for the war years, we have done much better than replace our withdrawals. In fact, over the 15-year period for which data are available, we have developed 1.6 barrels of oil to take the place of every barrel produced. This record certainly does not bear out the contention that we are running out of oil.

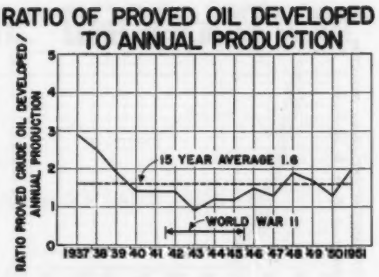
RATIO OF PROVED OIL DEVELOPED TO ANNUAL PRODUCTION
RATIO PROVED CRUDE OIL DEVELOPED / ANNUAL PRODUCTION
0
1
2
3
4
5
15 YEAR AVERAGE 1.6
WORLD WAR II
1937 38 39 40 41 42 43 44 45 46 47 48 49 50 1951

FIGURE 3

BASIS FOR THIS FORECAST

Although this statistical series is interesting and, without question, informative, my associates and I have come to the conclusion that a more reliable picture of our future oil production can be obtained from the opinions of the men who must find the new oil prospects to drill, viz., the geologists and geophysicists. In developing this forecast, we have consulted oil-finding people who work in all of the major producing provinces of the United States, and this forecast represents the consensus of their views. Estimates of future production potentials of the various areas have been cross-checked with one another, and have been revised and adjusted to what we believe to be a mutually consistent basis and one not in conflict with such statistical evidence as can be employed.

For purposes of this study, each of several groups of exploration people was asked to prepare its forecasts on the assumption that a market would be available for all the crude oil which could be produced at maximum efficient rate of production. With MER production rates as estimated, the number of future discoveries and wells necessary to produce at these rates can be derived. After preparation of these estimates, and after the demand rates which Mr. Boatwright will discuss in his paper had been taken into account, it became evident that more oil would probably be available than could be consumed if the fields should be produced at MER rates.

By a successive approximation procedure, it was then possible to estimate reserve producing capacity on a basis consistent with expected rates of production.

As a result of all of these adjustments, this forecast shows a substantial increase in reserve producing capacity over the next 15 years. If we continue in a war-like economy for the next several years, it may be desirable to provide this reserve producing capacity. If, on the other hand, conditions change so that this extra capacity is not needed, the exploration and drilling programs of the industry will probably be curtailed, and will thus postpone the finding and development of some of the producing capacity forecast in this study.

In considering these predictions, it should be kept in mind that geologists in the United States and Canada have been very successful in finding new oil fields during the past two or three years and are, therefore, optimistic about their continued ability to find oil. In the

past few years the reef fields of West Texas have come into production. Development of the Spraberry sand in West Texas has been commenced; important new reserves have been found on the flanks of salt domes along the Gulf Coast; large new fields have been found in the prairie provinces of Canada; new oil has been discovered in western Nebraska, eastern Colorado, and Utah; and, perhaps most important of all, a major new oil province has been opened in the Williston Basin. Had the present forecast been made four or five years ago, it might not have been so optimistic, and it is possible that a similar forecast five years from now might be more pessimistic. But, notwithstanding this inherent question of accuracy, the oil finders' appraisal of their future hunting ground is better than any outsider could possibly make.

The present forecast of supplies includes a considerable amount of oil attributed to secondary recovery by water-drive and gas-drive methods, but assumes no drastic change in these practices. The forecast contains no production which may ultimately be developed as a result of new secondary-recovery methods not yet perfected in field practice.

PRODUCTION AND AVAILABILITY

Our forecast of production of crude oil and natural-gas liquids in the United States for the next 15 years is shown in Fig. 4. Fig. 4 shows not only our forecast of production of crude oil and natural-gas liquids through 1967, but also our estimate of the nation's productive capacity. Several things are noteworthy about Fig. 4. First, we feel that domestic production of crude oil will continue to increase over the period we have considered and, second, that the industry will be building up its producing capacity faster than production; in other words, we shall be finding oil faster than we shall be using it.

We estimate that the industry in 1967 will be producing about 8 million barrels per day of crude oil and 1 million 100 thousand barrels per day of natural-gas liquids—a total of about 9 million 100 thousand barrels per day. This is an increase of about 2 million 200 thousand barrels per day over present levels, or about 33 percent. Natural-gas liquids are expected to become an increasingly important part of our supply picture as gas sales increase and pressure-maintenance projects come into more general use for increasing ultimate crude-oil recovery.

It will be noted that the nation's productive capacity has appreciably exceeded actual production except during the years immediately following the war, when release of the pent-up demand severely taxed the industry's capacity. At present we have reserve producing capacity of about 900 thousand barrels per day. Our forecast expects this reserve capacity to increase to about 1 million 900 thousand barrels per day in 1967, or about 21 percent of the daily rate of production at that time. Mr. Boatwright will have more to say about this in his discussion.

In summary of Fig. 4, it is our conclusion that the domestic oil industry will find enough oil in the next 15 years to meet foreseeable demand and, barring a major war with virtually complete cessation of imports, the industry will have a comfortable margin of producing capacity in excess of actual requirements.

In order to reach a producing capacity of the magnitude shown in Fig.

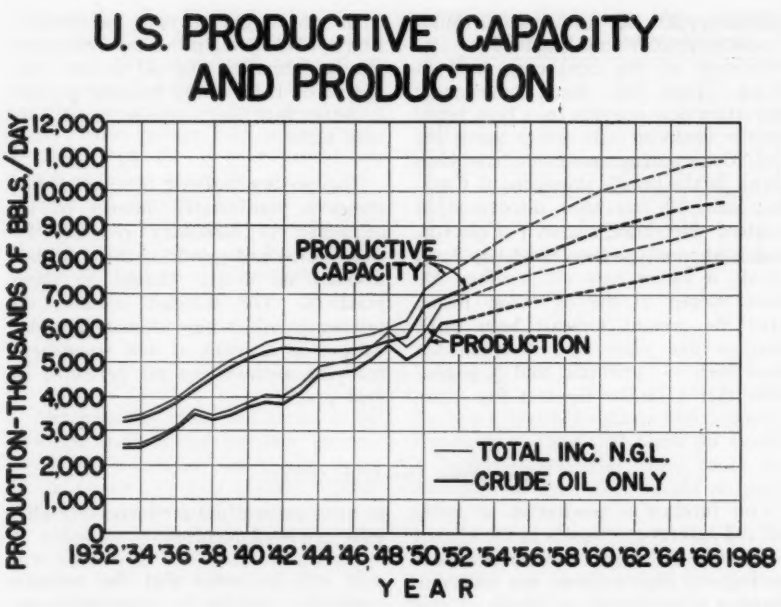

FIGURE 4

4, the oil industry of the United States must find and develop approximately 49 billion barrels of crude oil between January 1, 1952, and the end of 1967. As indicated in Fig. 5, this task should be measured by the industry's production, from its beginning to date, of approximately 42 billion barrels and total discoveries to date (production plus reserves) of about 71 billion barrels. Our forecast indicates that, by the end of 1967, cumulative crude-oil discoveries should reach 120 billion barrels, with proved reserves standing at 38 billion barrels—about 13 times the then current rate of production. If this task seems large, let me point out that, during the past 15 years (as shown in Fig. 5), the industry has added 39 billion barrels as compared with 49 billion forecast for the next 15 years. And it should not be forgotten that ours is a growing industry; we are producing more oil, drilling more wells, and doing more exploration than ever before. Today we are running almost 700 seismograph crews as compared with only 200 in 1937. More geologists are looking for

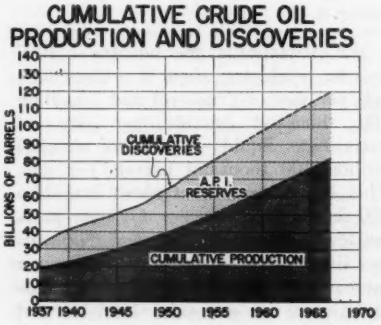

FIGURE 5

oil than ever before. Although figures on employment of geologists by the industry are not available, an indirect measurement is afforded by membership in the American Association of Petroleum Geologists. AAPG membership has increased from 2300 to 9300 in the past 15 years—a fourfold increase. And it should be noticed that all of these yardsticks do not take into consideration the improvement in quality of our effort.

In order to discover and develop these reserves, a substantial, although gradual, increase in drilling effort will be required. Although we forecast a sizable increase in exploratory drilling, the number of field development wells required will be not appreciably larger than at present. The total number of wells forecasted for 1967, viz., 62,000, appears to be easily within the reach of the industry.

Interesting, of course, will be the source of all this oil of the future. The following discussion will outline briefly the significant developments expected in future years.

PAW District I covers the eastern section of the United States. In this area the only states now producing oil are New York, Pennsylvania, West Virginia, and Florida. We are forecasting that this area will increase in production from about 69,000 bbl per day in 1951 to about 115,000 bbl per day in 1967. We expect that the major part of this new oil will come from Florida, and that the old producing areas of New York, Pennsylvania, and West Virginia will continue their gradual decline.

PAW District II covers principally the Mid Continent area of the United States. We are estimating that production in this area will increase from 1 million 176 thousand barrels per day in 1951 to about 1 million 490 thousand barrels per day in 1967. The major portion of this increase should come from North Dakota and South Dakota, for which states we are forecasting production at a rate of about 316 thousand barrels per day in 1967. At present there are two large-sized pools under development in North Dakota. Oil has been found in several different producing horizons in these pools, and 17 rigs are now actively drilling. We expect little change in production in other states of District II.

PAW District III includes states bordering the Gulf Coast from Alabama to Texas, plus the states of Arkansas and New Mexico. We are estimating that production in this area will increase from 4 million 119 thousand barrels per day in 1951 to 5 million 720 thousand barrels per day in 1967. We expect Louisiana alone to increase from about 697 thousand barrels per day to about 1 million 180 thousand barrels per day, with about 290 thousand barrels per day coming from offshore properties, as compared with about 19 thousand barrels per day last year. We expect to see Mississippi double its production from 105 thousand barrels per day to about 209 thousand barrels per day. We expect to see the Texas offshore fields producing some 68 thousand barrels per day 15 years from now. We anticipate substantial increases in production along the Texas Gulf Coast—from about 1 million 50 thousand barrels per day to 1 million 530 thousand barrels per day—and almost as much from the prolific Permian Basin of West Texas.

The large thick sands encountered along the Gulf Coast pinch out on the flanks of most of the known salt domes. Exploration in this region in recent years has shown production from such pinch-out sands to be very prolific, and we anticipate substantial increases in

production from this source in the future. Recent years, in West Texas, have seen discovery of the great reef fields of the eastern shelf, and there is every reason to believe that substantial accumulations of oil can be found in the Pennsylvanian rocks along the edge of the Central Basin uplift. Another significant development in recent years has been the discovery of Ellenberger production in the middle of the Permian Basin. Pegasus, Benedum, and Midland Farms are examples of such fields. There will be many more.

PAW District IV, which covers the Rocky Mountain area, is forecast as increasing in production from 297 thousand barrels per day in 1951 to 619 thousand barrels per day in 1967. We expect the Montana portion of the Williston Basin to grow to about 180 thousand barrels per day in the next 15 years, and Wyoming's production to expand a little more than 100 thousand barrels per day. Several important pools have already been found in eastern Montana, and a number of others are sure to be found in due course.

In PAW District V, which covers the West Coast, we expect the present rate of production of 1 million 52 thousand barrels to be maintained at essentially present levels throughout the forecast period. Production onshore in California will probably decline, but this should be offset by development of the California tidelands. Our figures do not include any production from the Elk Hills Naval Reserve, which is a major reservoir, but which probably will not be produced unless we get into an all-out war.

Although we have made no detailed forecast of the quality of crude oil which will be available in future years, there is some basis for belief that a higher proportion of low-sulfur crude will be available than has been the case in the recent past. Crude oil from the Williston Basin, from the offshore areas of Texas and Louisiana, and from the deep pays of the Permian Basin, by and large is low in sulfur content. These are the areas which should produce most of the additional oil which will be needed over the next 15 years.

NATURAL-GAS-LIQUIDS AVAILABILITY

The preceding discussion has been concerned principally with availability of crude oil, but recent years have seen a dramatic increase in recovery of liquids from natural gas. Gasoline-plant capacity in the country has expanded enormously in recent years due to the emergence of repressuring as a common tool for increasing recovery of oil from known reservoirs. These plants recover large quantities of liquefied petroleum gas and natural gasoline. The use of such facilities will undoubtedly expand. We expect to see more natural-gas-liquids extraction plants installed along the large interstate gas pipe lines to recover propane, butane, and heavier materials from gas streams intended for industrial or residential consumption. The industry's development of salt cavity storage will provide badly needed facilities for storing LPG during slack demand periods for later recovery and marketing during periods of high demand.

We are forecasting that production of natural-gas liquids will rise from 564 thousand barrels in 1951 to about 1 million 065 thousand barrels per day in 1967. The larger proportion of volatile liquids available may necessitate some changes in refining operations, but growth will be gradual, and adjustments to use of this raw material will be made over a period of time.

OTHER PROSPECTS FOR ADDITIONAL OIL

If it should develop that the industry is unable to find oil by historic methods at the rates predicted in this forecast, we still have several other strings to our bow.

Present methods of oil production, on the average, recover 25 to 35 percent of the oil in place in the ground. In fields where a natural water drive is present, such as East Texas, recoveries may ultimately be as high as 80 percent of the oil originally in place. In pools where a natural water drive is not present but where water injection can be practiced, recoveries can frequently be increased from 25 to 35 percent to the range of 40 to 60 percent of the oil in place. If technologists of the industry can devise means of substantially improving present recovery practices, we can add many billions of barrels to our known reserves at no finding cost, and can push even farther into the future the day when this country will be deficient in its oil supplies. This problem is being studied, and some of the ideas now in the laboratory or yet to be discovered may prove practical for field application.

The figures of our forecast assume a normal increase in water flooding, gas injection, and other conventional methods of secondary recovery, but they do not recognize the possibility of any increased production through application of techniques not now in commercial use.

There is a much larger area of this country which is potential oil territory than appears in the producing column today. Naturally, the oil industry has explored for oil fields in those territories which appear to have the best production prospects. But I should like to point out that the large areas of the Williston Basin of the Dakotas and Montana, and the Uintah Basin of Utah and Colorado, had no oil production five years ago. They are now being actively explored and developed, and their producing areas will be enlarged still more. Any day one of these other prospective areas, such as the Great Basin in Nevada and Utah, southeastern Colorado, the Salina Basin in Kansas and Nebraska, or any of several others, could break into the producing column. Improved techniques of seismograph and other geophysical methods, together with improvements in drilling practices, which would lower the cost of digging wells, could do much to extend the present producing area and productive capacity of this country.

OIL OUTSIDE THE UNITED STATES

This paper is primarily concerned with the availability of oil from domestic production for the refineries of the United States, but any such discussion would not be complete without some comment on the foreign oil situation. At present reserves of oil and natural-gas liquids in the United States stand at some 32 billion barrels, as compared with some 74 billion barrels for the rest of the free world; 52 billion barrels of these reserves are located in the Middle East; most of the balance is located in Venezuela and other South American countries.

At present the United States is importing a little more than 900 thousand barrels per day of crude oil and refined products. If production capacity of this country increases at the rates set out in this forecast, we expect to see a gradual increase in imports to about 1 million 420 thousand barrels per day in 1967. By and large, we expect most of the foreign crude brought into this

country to be processed in refineries along the East Coast. Although we expect Canadian crude-oil production to increase from about 132 thousand barrels per day in 1951 to 715 thousand barrels per day in 1967, we anticipate that imports of Canadian crude will be primarily for use in the Pacific Northwest and the area around the head of the Great Lakes.

Our estimates of foreign crude-oil production capacity indicate that there will be substantially more crude available to us than we shall probably permit to enter this country. As is well-known, importation of crude oil is a matter subject to governmental regulation, and governmental regulation is a field in which forecasting is more of a guess than a science.

CONCLUSION

In considering the future supply of oil for the United States, I have one other chart I should like to discuss, viz., Fig. 6. In Fig. 6 we have shown a comparison between gross income received from crude-oil sales and total expenditures for drilling oil wells. To obtain the gross income, we have taken the nation's annual production of crude oil and multiplied it by the average price per barrel. This gives a measure of the gross cash supply of the producing industry and, of course, disregards income from gas sales and other incidental operations, borrowings, and the fact that payments to royalty owners frequently are not re-invested in the business. We were somewhat handicapped in obtaining figures on well costs of the industry, because complete records are not available. It is easy to obtain the total number of wells and the average depth drilled, but it is practically impossible to obtain an average cost per foot drilled because of the wide variations between areas and the fact that drilling costs increase at least geometrically with depth. For purposes of Fig. 6, we have taken some figures published last year by H. J. Struth which show the total cost of all wildcats and development dry holes, and we have assumed that these figures are a representative sample of all wells drilled. This assumption is subject to some criticism, but I do not believe deficiencies in the figures are material.

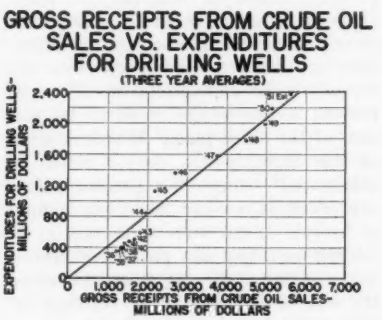

FIGURE 6

We have checked the relationship shown with several independent sources of information, and are convinced that the basic relationship depicted is correct.

It will be noted that Fig. 6 shows a direct correlation between money available to the oil industry and the money spent for drilling wells. The line indicates that the industry spends a little more than 40 percent of its gross income for drilling. Although no precise figures are available, a roughly equivalent amount goes into exploration and leasing, and the balance goes into taxes, overhead, profit, and general expenses. The correlation is excellent, except during the years 1944, 1945, and 1946, when the industry continued to spend more than normal amounts of money for wells even though the price of

crude oil was frozen at an unduly low level.

Now, as to the significance of Fig. 6, it indicates that drilling activity is related directly to industry income. If the oil-producing industry is to achieve the levels of production predicted in this forecast, it must have the money to do the exploration and development. If the government takes a bigger tax bite; if the depletion allowance is reduced or done away with; or if arbitrary and costly regulations are imposed to restrict freedom of activity, each will have a direct bearing on the industry's ability to find new oil. If the price of crude oil is fixed while drilling costs are permitted to rise, the total number of wells which can be drilled must necessarily be reduced. At this point I should like to remind you that drilling costs, because of inflation, increasing depth, etc., have increased almost fivefold during the past 15 years; that they have increased substantially since the war; and that crude-oil prices have remained unchanged since 1947.

In conclusion, it is my firm conviction that the domestic oil industry can supply sufficient oil to meet all of our needs for the foreseeable future; but, no matter whether the industry can do these things, the result will not be achieved unless the industry is permitted the freedom to do the job which has to be done.

PART II

INTRODUCTION

Mr. Swearingen and his associates reviewed the possible future productive capacity irrespective of what the demand may be. I started at the other extreme, and estimated what the demand might be irrespective of problems of availability. These estimates of demand were then made available to Mr. Swearingen so that he could determine the probable future production rates. Reflecting these probable future production rates, he was able to build his estimate of future availability by years—recognizing a normal or expected production rate. A comparison of probable availability with the future consumption level indicates that supplies are adequate to meet total requirements. This comparison also reveals the probability of surplus supplies, the extent of the margin of safety, and whether synthetic-fuel production is likely to be required during this time period.

The forecast of the extent of the market and the study of future probable supplies were not sufficient to answer all of the challenges which required consideration. If the petroleum industry is to achieve the full satisfaction of petroleum needs, adequate facilities must be available for moving crude oil to the refineries and finished products to the market. Refinery capacity must be adequate to process total needs, with a proper margin for security purposes. These additional considerations are also covered in this analysis.

The authors of papers such as these should either present the assumptions underlying their work, or they should indicate that the work is based upon the broad assumption that present economic controls will be eliminated and that an industry free to make decisions on economic considerations will be reestablished. We have followed the latter course. But there are, and will be, many economic problems which—depending upon the manner in which they are met—could greatly modify anticipated achievements. These will be touched upon briefly. Let us now turn to the probable needs for petroleum products.

TABLE 1

U.S. Total Demand

(Figures in Thousands of Barrels Per Day)

Domestic	1951	1955	1960	1965	1967	Increase 1967 Over 1951 (Per Cent)
Gasoline	2,987	3,545	3,910	4,230	4,350	46
Kerosene and distillate fuel	1,569	1,869	2,064	2,210	2,260	44
Residual fuel	1,544	1,648	1,716	1,823	1,860	20
Other products	943	1,238	1,490	1,727	1,810	92
Total domestic demand, all products	7,043	8,300	9,180	9,990	10,280	46
Total exports	423	165	125	120	120	−72
Total demand, all products	7,466	8,465	9,305	10,110	10,400	39

ANTICIPATED DEMAND

The forecast of petroleum demand has been made giving recognition to the nation's total output of goods and services. No attempt was made to time a business recession or recessions, although this possibility was clearly recognized. In reviewing a 15-year time period, I believe the basic growth factors of the economy to be more significant than annual deviations which may occur about that growth curve.

The anticipated growth of population, the expansion of industrial production, capital investment in new plants and durable equipment, the employment level, and other underlying basic economic trends were studied. Individual uses of petroleum were analyzed against that background. Total energy needs and the shifting proportion of the total supplied by petroleum, transportation requirements represented by number of units and consumption per unit, radiation units installed and requirements per annum, and industrial processing with petroleum products were analyzed from historical data and probable future needs. Agricultural and other off-the-highway needs for gasoline and other petroleum products were studied. All in all, several hundred indices of change were analyzed to the best of our ability in order to ascertain the probable future needs for petroleum products. You will be spared the detail of these separate studies, as we shall turn directly to the composite results (Table 1).

Let us refer only to the more salient features of this forecast (Table 1):

1. Total domestic demand for petroleum products is forecast to increase from 7,043,000 bbl to 10,280,000 bbl daily by 1967, or a 46-percent gain. Exports should decline as a result of increased refinery capacity built in foreign lands. Reflecting the influence of this decline in exports, total demand for all products should increase from 7,466,000 bbl to 10,400,000 bbl daily, or an increase of 39 percent.

2. The forecast of domestic demand for gasoline, representing a 46-percent expansion, reflects our guess of growing military needs, as well as the increased requirements for civilian uses. Incidentally, the growth in gasoline requirements would have been higher had it not been for the competition we anticipate from the use of liquefied petroleum gas by trucks, tractors, buses, etc.

3. The increase of 44 percent for kerosene and distillates reflects the growth of jet-fuel utilization, the continued trend to dieselization, and the growth of present uses and new uses for the product.

4. The forecast of demand for residual fuel represents the smallest in-

crease of any of the product classifications. Utilization of this product, by types of industries, presents contrasting trends—some increasing and some declining. Probably the most significant industry trend recognized was that oil-fired steam locomotives would be almost entirely converted to diesel fuel considerably prior to 1967.

5. The most significant increase forecast applies to "other products," including lubricating oils, asphalts, waxes, petroleum chemicals, coke, still gas, and liquefied petroleum gas. The sizable increase in volume of liquefied gas, representing a gain of 175 percent, explains the major proportion of growth anticipated for this class of products.

THE ADEQUACY OF SUPPLIES

Now let us turn to a comparison of demand with estimated supplies of crude oil and natural-gas liquids. This comparison is offered on two bases so that conclusions may be drawn which reflect the degree of conservatism of the individual reader.

TABLE 2

Domestic Availability Vs. Total Demand

(Figures in Thousands of Barrels Per Day)

Year	Domestic Availability of Crude Oil and Natural-Gas Liquids	Total Demand, Including Exports	Margin of Domestic Supply Over Total Demand
1950	7,123	6,812	311
1951	7,537	7,467	70
1955	8,792	8,465	327
1960	10,016	9,305	711
1965	10,736	10,110	626
1967	10,902	10,400	502

It will be noted from the comparison in Table 2 that purely domestic supplies will be adequate to meet total needs without imports, and will still afford the nation a protective cushion of about 5 percent. But this comparison is unrealistic to the extent that there will be imports of both crude and products. Striking a comparison on this basis, we arrive at Table 3.

Now it will be noted that the protective cushion ranges up to 2 million barrels daily, amounting to between 18 and 20 percent over requirements. The Petroleum Administration for Defense is now advocating for security reasons that reserve producing capacity be pushed to about 25 percent above total domestic demand, including imports. We do not feel that this level can be achieved without some major adjustments to the industry's drilling program. In fact, we doubt that the industry will be able to carry a margin of greater than approximately 20 percent over current demand.

There has been considerable study of production of synthetic fuels to supplement the availability of crude oil. Repeated study and analysis of this problem are healthy. To advocate building a synthetic industry, however, is to select the synthetic route as preferable to the traditional means of increasing supplies. This is a decision which should be based on economic considerations. I do not wish to enter into, or to discuss differences in, reports by committees, consultants, or the Bureau of Mines on this subject. But isn't the answer relatively clear? Men in petroleum are well-acquainted with synthetic-fuel production processes. Petroleum capital will build such plants as soon as the conviction has been reached that production of synthetic fuels affords a more attractive return on investment than alternate use of that capital in customary development. Thus economic considerations will de-

termine when synthetic plants will, and should, be built.

TABLE 3

TOTAL AVAILABILITY VS. TOTAL DEMAND

(Figures in Thousands of Barrels Per Day)

Year	Total Estimated Supplies of Crude Oil and Natural-Gas Liquids from Domestic Production, Plus Imports	Total Demand, Including Exports Minus Imports of Finished Products	Estimated Margin of Total Supply Over Total Demand
1950	7,610	6,449	1,161
1951	8,028	7,114	914
1955	9,492	8,123	1,369
1960	10,830	8,928	1,902
1965	11,652	9,637	2,015
1967	11,837	9,918	1,919

When may such economic conditions indicate that synthetic plant production may be anticipated? No one knows. In terms of total supply, there appears to be a healthy cushion of sufficient magnitude for the next 15 years so that any construction as of this date would be at tremendous social cost. Also it should not be forgotten that our estimates of future availability of crude oil and natural-gas liquids reflect economic pressures for increased supplies. If the government builds plants for producing synthetic fuels from shale, coal, or gas and thus competes with industry, this tends to reduce the private search for oil supplies from natural sources. If such plants are operated in competition with private industry and do not make money, then the total availability of oil is less than it would have been if the same amount of money had been spent for direct exploration. If these plants are not operated because they cannot operate at a profit, wastes are compounded to ridiculous amounts. And, to repeat, if they can be operated at a profit comparable with that earned from other sources of oil, oil men will build them.

PROBABLE CRUDE RUNS AND REFINERY CAPACITY

Total requirements of petroleum products will be supplied from several different sources. Imports of finished products, particularly heavy fuels, will continue to supply an important part of demand. Transfers from crude and natural-gas liquids will also supply an important segment of the total. After making these and other minor adjustments—such as losses, crude exports, and refined-product inventory changes—we find that the probable crude runs by years will be as indicated in Table 4.

TABLE 4

ESTIMATED CRUDE RUNS REQUIRED

(Figures in Thousands of Barrels Per Day)

1950	5,739
1951	6,494
1955	7,253
1960	7,878
1965	8,503
1967	8,763

Let us assume that the ratio of crude runs to total capacity in 1967 will be approximately the levels maintained during recent years. This gives us a clue to the probable refining capacity of the industry. On this basis, total refinery capacity in the nation will be approximately 10,700,000 bbl. This will require an annual expansion of total refinery capacity of approximately 250,000 bbl. Certainly this presents no unusual challenge to the industry in the light of what it has achieved since 1946—our average building rate per annum from 1946 through 1951 having been 320,000 bbl per day. And, when we think of total refinery building, we must recognize that the industry will have to replace obsolete equipment as well as add new capacity. Estimated expenditures by refineries alone in 1952 will probably exceed one billion dollars. I believe there is no question that the

industry will provide adequate refining capacity to meet market needs.

In connection with constructing new refineries, some interesting new developments will unquestionably be evidenced. Factors determining the economics of refinery location are changing. Technological progress of fuel reduction is resulting in higher yields of light products susceptible to pipe-line movement and in lower yields of residual fuels not susceptible to low-cost transport movement. This changed pattern of yields, and the ICC limitation on earnings on crude-oil pipe-line investment to 8 percent and the permissible rate of earnings of 10 percent on product pipe lines, are important factors in determining the location of a new refinery. Inasmuch as new crude producing areas must be connected to future markets, there are sound reasons for anticipating a greater dispersal of refineries—and this offers the advantage of decentralization of military targets, a greater dependence upon product pipe-lines, and a reduced relative dependence upon crude-oil pipe lines.

This brings us to a consideration of transportation problems.

TRANSPORTATION REQUIREMENTS

Increased quantities of crude oil and natural-gas liquids must be brought to the refinery, and the finished products must be moved from the refinery to the market. This means that transportation facilities will be expanded. Crude-oil pipe lines will be built from new sources of crude to present refinery centers, and to new refinery centers; whereas new product pipe lines will be built from new refinery centers into markets which are presently served by pipe lines, and into markets which are not today considered sufficiently concentrated to warrant expenditures for such facilities.

We cannot go into the details of probable future pipe-line construction from individual points of origin to individual destinations. Nor can the economic pressures which may come into existence be forecast with sufficient accuracy at this time to merit individual-project conclusions. This problem, therefore, has been approached purely on a statistical basis. It would appear that crude-oil and products trunk-line traffic will increase by some 400 billion barrel-miles. This means that, between now and 1967, the industry will build a net increase to its present pipe-line system equal to approximately half of present carrying capacity.

Another substantial consideration which needs to be recognized in the transportation factor is that the carrying capacity of ocean tankers will have to be increased. Adjustments of the carrying capacity of barges, tank cars, and truck transports will be made on a regular annual basis as may be needed by the market.

Thus our review of the probable 15-year future leads us to certain basic conclusions.

1. We feel confident that the future supply of crude oil and natural-gas liquids will be adequate to meet the needs of a greatly expanded market. Nevertheless, we also feel that the demand for a larger backlog of producing capacity will result in greater and greater exploratory effort.

2. Even though many have considered that the postwar refinery building programs were of a catching-up nature, it now appears that building at almost the average rate achieved since 1946 will be normal expectancy for the future.

3. Adjustments, changes, and constant expansion of transportation facilities will be needed in the future.

Our analysis gives us confidence that the industry should be able to continue to do the job which it has always achieved, viz., supplying all the oil needed. "Growth" is perhaps the one word which best characterizes the future of our industry.

A FEW MAJOR ECONOMIC CONSIDERATIONS

In the conduct of our study we encountered many economic uncertainties which had to be resolved by assumptions. The validity of our forecasts depends upon the accuracy of our judgments. We believe that you will be interested in these problems and in our conclusions regarding them. If subsequent events prove to be different from what we have concluded, then our prognostications would have to be changed.

Monetary Stability

We have assumed a greater degree of monetary stability than has been in evidence in the past five years. This is an essential requirement to the accomplishment of the objectives previously discussed. I do not desire to discuss the effects of inflation or deflation on future industry growth. However, attention should be called to the fact that we are now in that phase of economic evolution when confiscation of property is reaching into investment in capital tools. Perhaps we can best state it in this language:

a. Depreciation allowances for profit determination for income-tax purposes are inadequate to replace capital tools now in use.

b. The understatement of depreciation results automatically in a corresponding overstatement of reported earnings.

c. Reported earnings are subject to graduated income-tax payments.

Hence we are actually paying an income tax every year on a part of the capital invested in fixed plant facilities. Therefore, we are in a period of capital-tools confiscation.

Obviously expansion cannot be built soundly upon such a foundation. If this industry and other industries in this country are to achieve the growth needed to meet the requirements of a greater population and defense objectives, it will be necessary that a certain stability of the purchasing power of the dollar be achieved.

Financial Requirements

Most people look at an industry facing a substantial market expansion with considerable optimism. This is as it should be, but there is a problem which must be recognized. We, in petroleum, realize that frequently our expansion capital must be expended from two to probably six years ahead of the period of actual need. That is why there is truth in a tendency recently expressed by a friend of mine—that the greater our sales, the poorer will be our cash position. Petroleum is a heavy capital-requirement industry. Its cash is frequently drained off to provide expansion required in the future.

Very few people, either in or outside the industry, realize the magnitude of capital requirements which will have to be met to build for a future market of the size discussed. No one knows what the actual total investment will be. The best anyone can do is to approximate. Our approximations resulted in a staggering concept of future capital requirements. We believe that total future expenditures for explora-

tion and development of necessary reserves, for transportation facilities, and for refining and distribution needs will average approximately five billion dollars per year. In fact, we are looking at a 75-billion-dollar program. This estimate is based upon the 1952 purchasing power of the dollar. If inflation continues, the amount will be correspondingly increased.

We have assumed that the industry would finance this growth, but it cannot be financed from reserves and retained earnings. However, we believe it well for all members of the industry to recognize that financing industry expansion is one of our greatest future responsibilities. We feel that it is even more vital that people outside the industry appreciate the essentiality of the profit incentive, as well as the inescapable necessity of plowing back a part of earnings, if we are to continue to grow.

Price Freedom

What assumption should we make about future price regulation? We recognized that most of our historical pattern had been established when the economy was not subject to governmental price ceilings. We know also that prolonged price regulation leads to rigidities in an economy, and this inevitably retards growth. Hence we assumed that present price regulations as applicable to petroleum would not prevail for much of the 15 years under review.

This appears to be a logical assumption, because: *a,* supplies are considerably in excess of present rate of consumption; *b,* supplies are susceptible to substantial expansion both from domestic and foreign sources; *c,* the geographical distribution of supplies and the production rate of particular products are often adversely affected by insensitive price ceilings; *d,* price ceilings do not recognize growth requirements; *e,* a vast proportion of petroleum is now being sold at less than ceiling prices; and, *f,* the potentiality of increased foreign competition is ever-present.

In fact, we don't see why price controls on petroleum could not be removed right now.

HIGHWAY LIMITATIONS

The data we have projected on cars in use and consumption per car cannot be achieved on the basis of present highway capacity. This economy is built to a large extent on an unusual degree of freedom of movement and transport via highways. We are convinced that many new highways must be built; many of the present ones will have to be improved and modernized. Estimated expenditures for highway construction in 1953 range between 2.7 and 3 billion dollars.

We feel that such new transportation arteries as are constructed will have to be engineered with the same degree of skill and planning as that applied to private ventures. In fact, both the petroleum and automotive industries may find it desirable to establish a group of expert highway engineers to function in an advisory capacity to insure efficiency of highway planning, construction, and financing.

The American public will pay a fair cost for making these additional facilities available. This is adequately demonstrated by the financial success of turnpikes. Therefore, as a basic premise underlying our work, we have assumed that funds made available for highway construction will be used almost exclusively for that purpose, and that they will be wisely expended.

INDUSTRY KNOW-HOW

Money alone will not insure the growth needed. Money must be associated with industry problem-solving know-how. This presents a two-horned dilemma: *a*, broadening the training of more promising young men who will have to supervise the wider investments incident to a growth industry; and, *b*, retaining the productivity of some of our most successful industry members after the tax laws of the country have eliminated the economic incentive for further work.

The assumption regarding the first of these two was easy to reach. Larger capital requirements will necessitate careful supervision. This means that present management will have to train a larger number of leaders to follow them. It seemed a logical conclusion that many companies in the industry would select their more promising young men and shift them from position to position so as to provide them with the broad basis of training necessary to meet the leadership requirements of the future.

The second part of this problem is more difficult. Why should a skilled individual continue to strive for greater accomplishments when he is denied the fruits of his labor by tax laws? And yet we know that our economy must have the benefit of the productivity of this class. Hence we have assumed the continued active contribution of the most successful persons of our industry, even though we appreciate that their present economic incentives are grossly inadequate.

LABOR RELATIONS

The existence of monopoly places a deadening hand upon a company, an industry, and upon the total economy. One of the greatest satisfactions I have obtained during my life as an economist in the oil industry is the deep conviction that it is ruled by strong, keen competition. I do not believe that an objective student can study the behavior of this industry and reach any other conclusion. Strong competition must continue if we grow.

Management-labor relationships in our industry have traditionally been on a local or, at the widest, on a company basis. This has been conducive to progress, as evidenced by wages paid and employee benefits received as fine as are enjoyed in any industry. But efforts have been made to substitute bargaining on an industrywide basis. When industrywide negotiations come into existence, there is an ability to extort from the public, whether this ability is exercised or not. Interruptions of operations because of labor-management disagreement when on an industrywide basis are in fact actions against the public.

There are competitive advantages incident to good labor-management relationships. Many in this industry are most anxious to see these advantages preserved both for labor and management. For this reason, we assumed that the general pattern of labor relationship would not change.

DIVORCEMENT

Competition in the market over a period of many years has built an industry structure designed to meet best the needs of the market. In many cases individual firms have worked toward an integrated pattern for the purpose of supplementing the market organizational function of competition. This has

resulted in various degrees of integration on the part of the vast majority of firms engaged in the petroleum industry.

I recognize that many organizations feel that the controversy involving integration does not touch them, but it does—either through ownership of transportation facilities, ownership of retail outlets, or ownership of an interest in more than one phase of the industry.

There is a suit now pending which seeks to force a segregation of marketing from other phases of the industry. None of us knows how far this effort will go. We are confident that it is an effort to modify a structure which has been built as a result of competition in the industry. It pleads that additional curbs, or barriers, to the free flow of capital and effort be introduced with respect to the petroleum industry. Therefore, if atomization of this industry results from either judicial or legislative action, the forecast which has been presented is no longer valid. A chaotic condition not subject to the same economic laws which have existed in the past will be brought into being, and the premises upon which the forecasts were based no longer exist.

REWARD TO CAPITAL

This is an extremely complex subject to attempt to cover in a brief paragraph. Normally, we think of the claimants upon a productive capacity of an economy as being labor, capital, government, and consumers. Labor receives a wage for its hire; capital receives an interest or dividend; the government receives its portion through taxes; and the consumer should receive his portion through greater real purchasing power of the dollar because of lower prices. But all laborers and all providers of capital are also consumers. Therefore, it is difficult to segregate the consumer's share of the output of goods and services. In reality, if we recognize this overlapping, we could say that the claimants are but three, viz., labor, capital owners, and government. Of these, government has received the greatest rate of increase through higher and higher taxes. Labor has received an increasing proportion of gross national production. The providers of capital have received a diminishing proportion.

We have already seen the essentialty of tremendous capital outlays on the part of this industry. To achieve this growth is to the benefit of labor, government, and the providers of capital. A more equitable sharing of the fruits of production is a prerequisite to continued growth. We believe that rewards to capital have passed the low level, and that the future will see increased interest rates. Hence we have assumed that the capital-supplying segment of our society will be more adequately compensated in the future, and that a more well-balanced participation in gross national production among capital, labor, and government will come into being. It must, if the forecasts are to be realized.

CONCLUSION

It has been a real pleasure to bring together these thoughts concerning the outlook for petroleum supply and demand, and to present them to you. I am sure you realize that the authors alone could not have prepared all of the supporting evidence reviewed. There have been many collaborators, both in

the company and outside. We should like to express our appreciation to them for their invaluable assistance.

But, as to the forecast, we feel that there must be a word of caution. The industry alone cannot insure accomplishment of these objectives. If the American people will create an environment characterized by monetary stability, free prices, intelligent labor relationships, and a sound highway-development program, this industry will supply the petroleum needed to meet full requirements.

A STUDY ON CAUSES OF SURFACE DAMAGES ON SHIP PROPELLERS

ENGEL GALTUNG

THE AUTHOR

Born 1906 in Norway; Graduated Naval Engineer, Norwegian Technical University College of Trondheim, Norway, Industry-economist, The Stockholm University College of Economics, Sweden, Metallurgist and Foundry Trained at Steel Mills and Metal Works, Naval Architect at The Stockholm Navy Shipyard, Sweden, Vice President at the Gaevle Shipyard, Sweden. In 1932 he studied European propeller factorying in Great Britain and Germany with Norwegian State Scholarship. During World War II, he made the first magnesium-alloy-die-castings for the Swedish Air Forces (after metallurgical investigations). 1935-1937 he made special investigations (to make suitable refractory) resins for the casting of naval steel castings, especially propellers.

I, the author, wish to explain my great debt of gratitude to Statens tekniska forskningsråd, Stockholm (The Swedish State Council of Technical Research), that by making a grant for the purpose, made this investigation possible and to Techn. Doctor Sven Brennert and Professor John Tandberg, Stockholm, who by discussions on the matter led me out from a certainly wrong path at the start of solving the task in 1949, and to the staff of the Library of Kungliga Tekniska Högskolan, Stockholm (The Royal Institute of Technology), that with great readiness and willingness helped me to find sources in this rather intricate matter in naval architecture.

During my work as a propeller designer, from 1931 I observed that surface damages on ship propellers sometimes looked like results of mechanical attack and sometimes like such deterioration of the material, which is to be seen on metallic surfaces exposed to acids with dissolving power for the metal in question. Studying the naval literature, available in the thirties, I found no answer to the question, whether the surface damages were a result of mechanical attack or chemical or both of them. I looked for remedy for surface damages.

With the explanation "surface damages" I here mean surface damages due to the contact with water, not ice or solids.

According to the literature available in the thirties, the opinion among naval engineers and shipbuilders generally was that the surface damages experienced were a result of mere water hammer effect set up by cavitation in water. Some authors have used the word "cavitation" in connection with the cavities, i.e., the damages in the propeller material. Here the word cavitation, as now is usual, is reserved for the phenomena in general, the forming of cavities in the water, either they are formed as gas bubbles or by extension of the natural cavities in the fluid itself or the water is lifting from the surface leaving a vacuum, if that were possible.

Regarding the different types of cavitation experienced in cavitation tank testing, the sheet cavitation and the burbling cavitation, I have not found any explanation as to the causes of the occurrence of the one or the other. Generally the sheet cavitation is experienced on propellers with great blade breadth and therefore relatively thin blade sections, and the burbling cavitation is generally found on narrow and medium blade breadths. In the stroboscopic lighting at the tank testing the sheet cavitation phenomenon can be seen with the water lifting from the blade surface, the water surface being like a mirror without bubbles. The burbling cavitation gives an opaque water stream from the point of starting cavitation, due to a great number of bubbles formed over a small area at once.

No plausible evidence has been given to the cause of the two types of cavitation.

Studying the dissertation of Eva Ramstedt, Uppsala (12), I arrived at the conclusion, that the sheet cavitation, with the mirrorsurface of water, lifting from the propeller surface, is occurring, when the adhesion between the water and the propeller surface is more than compensated by the inertia forces lifting the water away and the procedure is effected in such a mild way that the cohesion in the water itself, with its gas contents is sufficient to keep the water together. The burbling cavitation then would occur, when the lifting forces are acting in such a way, that they are rather breaking up the tensile strength of the water than lifting it as a unit from the propeller surface. Studying the well known Göttingen Aerofoil sections, it is clear that the pressure, involved by the inertia forces on the fluid is widely different on thin profiles and thick sections. Any quantitative knowledge of the strength of water by propellers and what forces are rather breaking up the water than lifting it as a unit from the propeller surface seems not to be available.

A preliminary general survey on published Research results on the mechanism of cavitation was made in 1952 by Civiling, (the Graduated Engineer), Rune Lindgren for a seminary meeting at the Royal Institute of Technology (KTH), Stockholm on January 14th, 1952, but no results showed the difference between the observed sheet cavitation and the burbling. It is not known what type of cavitation is the most disadvantageous with regard to material destruction. But as it can be shown by laboratory tests on material destruction by vibrating specimens in water, Beeching (1), and Knapp and Hollander (13) has showed that a burbling cavitation is a phenomenon of vibration (pulsation of bubbles). One could expect the burbling cavitation to be the worst destructor. In such cases, where the water is lifting totally from the propeller surface and the vacuum cavity formed over the whole section does not collapse before the whole section has passed, it is difficult to imagine mechanical attack on the blade surface.

The water hammer effect seems to be the result of severe blows by the water on the propeller surface, when the bubbles formed in the fluid are col-

lapsing on the surface itself. According to Ramstedt (12) it is found that water has a certain tensile strength, also when the water contains gases dissolved. When the tensile strength is reached by the inertia forces, bubbles are released, and the inertia forces will expand the bubbles until equilibrium is reached. Then the negative pressure forces in the bubble will accelerate the water surfaces around the bubble together, and if the bubble is formed directly on the propeller surface, the outer water surface will be accelerated towards the metal surface and give off a heavy blow. Some elongation has been measured, when water is stretched out to the tensile strength. There is also some compression measured, when the water is affected by pressure forces, i.e., there is some elasticity. Also the propeller material has some elasticity. When the bubbles are collapsing, some part of the kinetic energy will be absorbed and be converted into heat, but some part will be absorbed by the elasticity and accelerate the water out again from the center of pressure-forces, and a bubble, somewhat smaller than the original is formed again. This might be the cause of the phenomenon photographed by Knapp and Hollander — the pulsating bubble. As water is a "hard" material with very narrow compressibility, the forces involved seems to be of a great order of magnitude, and a mechanical destruction of the material by mere water hammer effect is probably possible. This is evident from the cavitation destruction of glass by distilled water, whereby no chemical effect is to be expected.

It is a common experience, that the cavitation damage on propeller surfaces is increasing with increasing degree of load. With load I here mean also the local load on certain areas, according to the measurements of pressure around, for instance, aerofoil sections. It is a general opinion among naval architects and shipbuilders that the problem of the cavitation surface damages arose when the first heavy loaded propeller was designed. This is true as to the quantitative part, but qualitatively the problem seems to be as old as the propeller as a design. This is evident from inspection of the world's oldest existing propeller, exhibited in 1952 at Tekniska Museet, Stockholm, (The Technical Museum of Stockholm), the propeller made by John Ericsson and brought over to Sweden from U.S.A. This propeller has, although naturally not heavily loaded, suffered from surface damage. The type of the damage seems to be of the electrochemical type. The material is a magnetic ferro alloy.

Essential for the propeller designer is however that propellers are found to suffer from surface damages, although the design according to known methods of calculation and testing were regarded to run cavitation free. This gives some evidence to the theory that propellers could have surface damages without being affected by water hammer effect. But there are still at least two possibilities:

1) That cavitation really exists under *service* conditions in spite of tank testing and calculation results.

2) That the surface damages are a result of chemical attack.

If cavitation in the reality existed, erosion could be expected. This is evident from the many research works regarding investigations of the durability of materials in venturi- and vibratory tests, for instance. (1) Beeching (1) investigated the resistance of different current propeller materials to water hammer effect set up by vibrating specimens. From the list of results one observes that the most resistant materials are the copper-nickel alloys, the aluminum bronzes and the high tensile brasses (generally manganese bronze). But these materials are also the most resistant to chemical attack. This is an experience from my work for the Swedish Metal Works.

If cavitation is not present, it is natural to look for chemical or electrochemical causes of destruction.

At the reading of the paper of Beeching (1) there was a discussion, where Dr. U. R. Evans, of Cambridge University took part (1942). On page 255 in (1) he states that the damages are a result of conjoint action between mechanical and chemical agencies. I cite his share to the discussion:

"The relative importance of the two agencies will vary with the conditions, and the situation is complicated by the fact that each agent of destruction will aid the action of the other. The author rather emphasizes the way in which corrosion facilitates the mechanical attack; without opposing this standpoint, it may be said that mechanical action may sometimes permit the continuation of corrosion where it would otherwise stifle itself.

"It has been proved by many methods (electrical, gravimetric and optical) that even at ordinary temperatures clean metal rapidly combines with oxygen or other non-metals, but that, in many instances, the film formed begins to stifle attack before it even becomes visible; in such circumstances, the metal is said to be resistant. If now at a point the film is continually cracked or dragged away from the surface as it is formed, the stifling will not occur. During the high-frequency vibration of metal in liquid, as in the author's admirable work, there is a severe *pull* upon the metallic skin during the halfcycle when the vacuum bubble is forming, followed by a severe *blow* during the collapse. This would seem to be just the sort of action that would prevent stifling and allow corrosion to continue, although the aspect of the damage will be quite different from that of static corrosion. Such a form of destruction should be regarded as "conjoint action"—of which corrosion fatigue is just another example—and discussions as to the shares of the damage attributable to chemical and mechanical agencies respectively, are unnecessary and possibly meaningless."

This point of view by Dr. Evans was new, 1942, in the available literature about cavitation. According to this theory it can be explained why cast steel propellers are suffering more from surface damages within the cavitation area of blades than the same design cast of, for instance manganese bronze.

The reason for this might be that the oxide film is dragged away as it is formed within the cavitation areas and therefore the chemical attack has free access to the fresh iron. As manganese bronze is more resistant to the chemical attack by sea water than cast steel, this makes a simple explanation of the phenomenon, that surface damage practically disappears, when a steel cast propeller is replaced by a manganese bronze propeller made after the same design as the steel casting, this in spite of, that a cavitation area might be calculated according to the circulation theory or can be observed in cavitation tank test. In such a case the water hammer effect is sufficient to drag off the oxide film within the cavitation area on the steel casting, but not sufficient to destruct the manganese bronze material mechanically.

But still it is not clear whether surface damage might occur also when no cavitation water hammer effect is dragging away the oxide film formed. It has really occurred that steel cast propellers suffered from severe damages, although no cavitation was expected. The damages are observed on propellers, which have been in service, but not on propellers, which have not been in service, although they have been placed on the shaft. Such observations have been made on ships, which are not in service during the winter periods.

There seems to be still some cause of damage that has to do with the con-

tact with water in flow, but this cause is not present, when the propeller is at still stand, at least not to any great extent comparatively.

There is also a problem around the full-cavitation propeller, where the oxide film probably would be dragged away all over the propeller blade surface. Such propellers are often suffering from damages at certain points, for instance at the blade roots, where the forces by water are expected to be lower than at the outer blade areas.

For the understanding of the matter it was natural to look for electrochemical causes. It was in 1949 proposed by Dr. Brennert, Stockholm, that a blade should be built of nonconductive material and in this blade should be built in electrodes reaching the surface at different points, hydrodynamically equalizing the different radii of a real propeller blade. By high sensitive electrical measuring instruments one could investigate whether an electromotive force is set up between the electrodes, affected by water streams of different speeds; but before such an experiment would be started, it should be investigated whether such investigations earlier were made or anything was published, that could substitute the proposed experiment.

It became my task to make that investigation.

For this purpose and for understanding the theories the 16 publications named in the bibliography to this report were studied. There is a lot of literature on this matter, and I had to concentrate upon a few publications giving answer to the question, whether surface damage can arise without cavitation and whether similar experiments as the proposed were made earlier.

In a publication (*2*) it is shown on page 93 already in 1914 that Ferro-oxide has a potential difference of 0.09 volts against "fresh" iron in an electrolyte 1 cm^3 10 percent H_2SO_4 to 1.5 liters of neutral 1/10-normal KCl solution.

For the understanding of the following reasoning it is important to keep in mind that the oxide is electrochemically nobler than the metal from which it is formed. This gives explanation to the pitting-phenomenon. This means that the oxide film has been broken up at a certain point and an electrolysis is set up between the naked metal surface as an anode and the surrounding oxidated main surfaces as cathodes. The water "hurrying" away over the surface, oxidates the surface more than the bottom of the initiating hole in the oxide film, where it is broken up.

Applying this to a propeller, there will be an anodic area, where the nobler oxide film is broken as well in the case of pittings as the general loss of material within the cavitation areas.

It is not necessary that the oxide film is dragged off. It is sufficient that the film is produced to a lesser extent at one point than at another point. The most oxidated areas will probably be the cathodes, and the cavitation areas will be the anodic part of the system.

If the water hammer effect is not sufficient to drag off the oxide film, there could still be corrosion. If burbling cavitation is present, there are a lot of bubbles produced. As will be shown below, the oxygen dissolved in water has a much greater oxidating power than oxygen in air. Thus there will be a less oxidated surface within the cavitation areas, as this surface is overflown by water mixed with air, and which has less oxidating power than water with chemically dissolved air.

As mentioned above, I did not find any indication in the literature, making probable, that the proposed investigation and experiments were made earlier. But I found publications with such results, that if they are combined, evidence is given to the theory that there is an agency, probably of electrochemical nature, which makes certain blade parts nobler than others. To explain this, I will discuss the principle of

"DIFFERENTIAL AERATION"

According to Evans (3) differential areation is set up, when two electrodes of the same material are placed in an electrolyte and a porous wall is placed between the electrodes, Fig. 1.

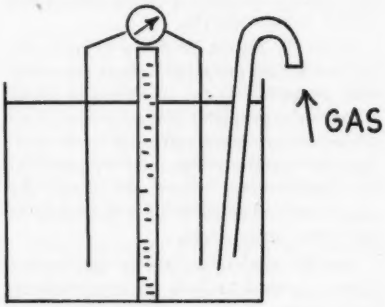

FIGURE 1

The porous wall permits electrolysis but not appreciable mechanical disturbances from one cell compartment to the other. It has been found that when air or oxygen is blown into the one cell compartment, the electrode in that compartment becomes electrochemically nobler than the undisturbed electrode. An electromotive force can be experienced between the free ends of the electrodes. It has been found also that blown-in-air gives a certain current and that more air per unit time gives a greater current. Further it has been found that oxygen blown into the cell gives more current than air, and oxygen blown in by high pressure, gives still more current. The electric current is increasing with increasing supply of oxygen.

On a propeller the air bubbles are formed within the cavitation areas. This would lead to the conclusion that the air or the oxygen directly oxidates the surface of the electrode. But it is experienced that the anodic area is just the cavitation area. It has been mentioned by Dr. Brennert at discussions on the matter, that one will experience an electromotive force also, when nitrogen is blown into the one cell compartment. It is not probable that nitrogen at the temperature in question combines with the metallic electrode, and if it could, it is not said that nitrogen will combine with the metal, so that this layer would be nobler than the metal itself. The phenomenon that a current is set up when nitrogen is blown in, seems to depend upon oxidation by the oxygen dissolved in the water. From the experiments of Auerbach (4) it is evident that it must be the oxygen in the water (dissolved oxygen) that makes the disturbed electrode nobler than the other, when a gas is blown into the one compartment. The nitrogen blown into the cell probably only involves a mechanical disturbance in the fluid, so that permanently new *fluid particles* are contacting the metal surface and is giving off a share of oxygen. The undisturbed electrode gets oxygen only from the nearest layer of electrolyte and the diffusion of oxygen—to the metal is so slowly effected that it can not concur in oxidation with the rapid oxygen supply in the disturbed compartment.

The fact that oxygen blown-in gives quantitatively more current than air, and that the quantity of current increases with increasing oxygen supply to the cell compartment, could be explained in that way, that it is the oxygen dissolved in the water, that oxidates the metallic surface, but the oxygen blown-in, is partly dissolved in the water. After having been dissolved it is probably given off to the electrode.

Auerbach has built in electrodes in a pipe and measured the potential differences set up by varying the speed of flow in the areas of the electrodes. According to Auerbach it was known by Helmholtz that a moving electrode set up a potential higher than an electrode at rest.

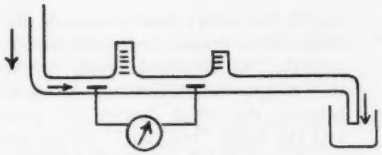

FIGURE 2—The Experiment of Auerbach.

This gives evidence to the theory, that it is the relative movement that causes the potential differences set up.

But in 1930 Auerbach had naturally not known about the principle of differential areation, published later. He says in his report, translated from German:

"To what an extent other influences, for instance gas contents, etc., plays a role, should be made clear by special investigations.

"Under all circumstances these conditions are worth great attendance."

Auerbach has found: (my remarks within brackets). See Fig. 2.

1) currents are set up independent of the nature of the electrolyte, also when distilled water is used. (Dissolved oxygen is to be expected also in distilled water. It is not easy to get rid of it and new charges will replace it, if by any means withdrawn).

2) The polarity of the combination electrodes, electrolyte and measuring instrument is ruled by the place of electrodes relative to the flow. (Probably the first reached electrode gets more oxygen than the next, which can not get more than maximum the rest of dissolved oxygen in the fluid).

3) If the flow is either laminar or turbulent at both electrodes, only small potential differences are set up, corresponding to the difference in speed of flow. (That electrode which has the greatest relative speed to the electrolyte gets more oxygen per unit of time than the other electrode and therefore the electrode with the greatest speed is expected to be the nobler one).

4) If there is a laminar flow over one electrode and turbulent over the other, great potential differences are set up. (This might be explained by the fact that in the case of laminar flow, only the nearest water particles give off some oxygen to the electrode, but in the case of turbulent flow there is an intense change of water particles reaching the surface of the electrode in question. There is however, one particular in paragraph 4, which is contradictory to paragraph 2 here. Auerbach has found that the polarity is ruled by the place of the electrodes relative to the flow. This is contradictory to the statement that great potential differences are set up, if there is laminar flow over one electrode and turbulent over the other. Because, if the trailing electrode is affected by turbulent flow, that electrode will be nobler than the leading. But if the *leading* electrode is affected by turbulent flow, *that* electrode will be the nobler. This is evident from Evans [(3) p. 274], who states that, when the oxygen supply is changed from one cell compartment to the other, the polarity will quickly be reversed.

The explanation to the fact that Auerbach arrived at the conclusion that the polarity is dependent of the place of the electrodes in the flow direction, seems to me to be a result of local particulars regarding the measuring apparatus. Probably it was constructed in such a way that the turbulence, when it started, always occurred first at the leading electrode for instance. This has to do with the dimensions of the pipe constrictions at the electrodes. It is not mentioned in the report, which of the electrodes first gets the turbulent flow.

Now, combining the principle of differential areation according to Evans (3) with the measuring re-

sults according to Auerbach (4) I arrive at the following conclusion with regard to propellers:

A) The relative speed of flow over a propeller blade is naturally dependent of the radius of the section concerned.

B) That section of blade, which has the greatest speed of flow, either laminar or turbulent is the nobler one.

C) If one section has laminar and another section turbulent flow, the section with the turbulent flow will be the nobler one in that case. Accordingly there is a chance that propeller blades might suffer from surface damage although cavitation, which by water hammer effect is dragging away oxide films, is not present. They will suffer from surface damage, if the material concerned has not sufficient resistance to corrosion initiated by the electromotive forces set up between the sections, affected by uneven flow. According to Brennert, (6, 7), it is necessary to apply a certain initial electromotive force to perforate the passivating skin on, for instance, stainless steels. Therefore, *if* the *potential difference,* set up by the uneven flow, say by turbulence over one area and laminar over another, *is* sufficient to perforate the oxide film of the material concerned, electrolytic corrosion will start. To what an extent the potential differences set up in this way really *are* so great that they will initiate perforation of the oxide film in the less noble area, is not known. This should be measured by experiment according to the proposal: propeller blade with electrodes built-in.

In the case of small propellers with narrow bosses and great number of revolutions there seems to be a chance that there is a turbulent flow at the outer blade areas, but a laminar or unstable flow at the bosses. According to the theory now presented, this might be the reason for the material destruction at the blade root, namely that a potential difference is set up between the outer "turbulent" areas and the inner "laminar." As the material near the boss also is the most easily soluble part of a propeller made by casting, because of the coarse grained structure there [Evans (3) p. 457], a started attack in those areas will soon lead to deep holes, as, the deeper the holes are growing, the less effective the oxidation will be in the bottom of the holes, and an accelerating corrosion is now set up between the non- or less-oxidated bottom of the holes and the better oxidated main surface outside the holes. Fresh water supply to the bottom of the holes could not be as effective as on the original surface. This might lead to the blades falling off the bosses, as also fatigue and stress corrosion will concentrate in the still decreasing material section, which has to absorb the service forces.

This is my conclusion, as a matter of opinion, based upon available research results, but not a matter of fact in the case of propellers:

1) There are potential differences set up on a propeller blade also without cavitation.

2) The magnitude of the potential differences set up might be sufficient to initiate corrosion, that is accelerated by "secondary invaders," namely the electrolysis between the oxygen poor bottom of the started pittings and the better oxidated surface around the pittings in conjoint acting with the fatigue and stress corrosion.

Regarding the propeller materials I arrive at the following conclusions:

1) If cavitation is present, the oxide film ought to be of a type that is not easily dragged away from the surface, and it ought to be tight in order

to prevent electrolysis between the metal and the surface oxide layer. That will be the task of the material experts to compose such materials.

2) If cavitation is not present the oxide film of the material ought, at least, to have sufficient resistance to perforation by the electromotive force set up between areas of different speed and type of flow. (This is true also in the case 1).

The durability of the propeller material seems to be dependent of the oxide film, i.e., its resistance to mechanical destruction and to perforation by electrolysis. Its resistance to perforation is directly proportional to the voltage necessary to apply to break up the film and start electrolysis.

It occurs that, if cavitation is unavoidable, surface damage would also be unavoidable, as no cavitation-damage-safe material is known. If, by design, the cavitation is avoided, much has been gained, but still the electrochemical agent is present. If one should try to do anything to that agent it might be to arrange for either laminar or turbulent flow all over the propeller surface, not partly laminar and partly turbulent flow, involving the great potential differences between the areas concerned.

A smooth surface will help to avoid initial differential areation (oxidation) at the top and the bottom of scratches and at the bottom and edge of holes.

About propeller materials of today there seems not to be much more to do, but it ought to be tried to make oxide films thicker by oxidating agents.

By development of new materials the requirements, in the case of metallic materials, will be: Mechanical and electrochemical resistant oxide films and a fine grain structure. The fine grain structure is not easily obtained in the thicker sections and the bosses of great propellers. Unfortunately a number of destruction-facilitating conditions are concentrated near the bosses, namely the greatest stress, the most coarse grained structure, the slowest solidification of the molten alloy by casting, involving plenty of time for the alloy-components to build up in crystals of widely different internal electric potentials, facilitating intergranular attack, weakening the section quickly after the occurrence of pittings, which might start as a result of poor oxygen supply to the inner sections compared with the supply to the outer sections, this as a result of difference in circumferential speed of flow and difference in wake. The oxygen supply is regarded to be increasing with increasing shifting of water particles giving off dissolved oxygen, thus the dependence of the speed of flow, as observed by Auerbach (4).

If my theory, that propellers might suffer from surface damages although there is no cavitation present, and with disregarding of the static corrosion of the material at still stand, is right, new factors should be brought into the propeller calculations to avoid the occurrence of mixed turbulent and laminar flow on the same propeller. But before one would take the step to complicate the propeller calculations in that way, it should be investigated, whether the electromotive forces set up by uneven flow, really are of such a magnitude, that they will perforate the oxide film on current propeller materials. Such experience is expected to become available from experiment according to the proposal of Techn. Doctor Sven Brennert, Stockholm, i.e., propeller blade with built-in-electrodes, with possibility to vary the intensity and type of flow, and it should be made partly under linear flow and partly in flow involved by rotating propeller, as there are special vortices in the flow in the case of rotating propellers, which might influence the oxygen supply to certain areas near the bosses.

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The studying of 14, 15 and 16 gave no result in trial to find papers describing experiments, which might substitute the proposed experiment with propeller blade with built-in-electrodes.

REVIEW OF SURFACE FINISH LITERATURE

ACKNOWLEDGMENT

This article, by Mr. JOHN W. SAWYER of The Bureau of Ships, Department of the Navy, was published in the September, October and November 1952 issues of "Machine Design."

During recent years the importance of surface roughness has increased materially. Factors to consider in properly evaluating surface finish of a material are numerous and vary from one field of use to another. Since the state of a surface may have some bearing on fatigue, corrosion, strength, friction, manufacturing cost and performance, the machine designer is usually vitally interested in one or more of these factors.

Work in the field of surface finish has been accelerated recently. Instruments and methods for producing and measuring desired finishes have been improved and new ones developed. The effect of finishes on machine performance has been studied and evaluated. Research and development work in the field has been undertaken by a number of industrial organizations as well as government agencies in the United States, Canada, Great Britain and other countries.

Many papers have been published on the results of investigations in research, engineering and manufacturing. The published material covers a variety of subjects including: instruments, methods of measurement, symbols, geometric standards, manufacturing methods, machinery, fatigue, corrosion, friction, cost and others.

This material is available in both technical and trade journals. The problem of covering a particular subject, however, is one that could require an expenditure of considerable time. In order to assist those who find it necessary to study recent literature on surface finish, the author has reviewed some three hundred articles and abstracts that were published during the years 1945 to 1951 inclusive. Approximately 220 of these have been recorded and are presented in this paper.

The articles presented here have been indexed in two groups: the abstracts themselves and a subject index.

The abstracts are listed by year and generally in order published. Each article is numbered. The numeral preceding the dash indicates the arrangement in this paper; the numeral following the dash indicates the year published. To illustrate the numbering system, article 16-49 is number 16 published in 1949.

The subjects covered by the various papers have been indexed. This index, to be published in a future issue, is alphabetical. As an example, under "Q" the subject of "Quality Control" lists, among others, article 19-48. This number refers to the article designated as number 19 published during the year 1948.

It is realized that in this review some publications may have been overlooked. However, the writer has attempted to include all material that he considered of interest. It is hoped that the information presented will be of material assistance in locating subjects of particular interest in the field of surface finish.

ACKNOWLEDGMENTS

The writer wishes to express particular appreciation to the Engineering Index, Inc., The H. H. Wilson Co. and the American Society for Metals for permission to use abstracts from their publications. The assistance of these organizations was of inestimable value in the preparation of this review. These three sources are identified in the abstracts as follows:

Engineering Index .....EI
Industrial Arts Index of
The H. H. Wilson Co.....IAI
American Society for
Metals .....ASM

Permission of the Department of Defense to publish this paper is acknowledged.

1951

1-51. "Visual and Optical Evaluation of Metal Surfaces"—Helmut Thielsch; *Metal Finishing,* v. 49, May 1951, pp. 54-61. Various methods of evaluating surfaces of metal are reviewed. Optical methods include: sight, projection, optical comparator, rigid replicas, lightfield illumination, optical sectioning, cross sectioning, taper sectioning, binocular microscope, stereomicroscopy, dark field illumination, pliable replicas, interferometry. Photomicrographs, tracer recordings, photographs, tabulations presented. Chart compares various methods.

2-51. "Surface Finish Standards"—T. E. Cassey and J. W. Sawyer; *Machine Design,* v. 23, May 1951, pp. 137-140. Uniform practice of specifying surface roughness, waviness and lay, as adapted by the U. S. Department of Defense.

3-51. "Contour Mapping of Optical Surfaces with Light Waves"—*Product Engineering,* v. 22, n. 7, July 1951, p. 155. Method of contour mapping of precise optical surfaces developed by the National Bureau of Standards.

4-51. "Engineering for Producibility"—Roger W. Bolz, *Machine Design,* v. 23, n. 8, August 1951, pp. 150-152. Includes chart showing basic machining processes, their overall and normal commercial range of surface roughness, and their accompanying range of practical dimensional tolerances. Other charts show overall and average range of natural surface roughness characteristic with the nonmachining processes, and characteristic maximum surface roughness for common machine parts.

5-51. "An Instrument for Automatically Recording Waviness of Surfaces"—C. W. Medhurst; *Journal of Scientific Instruments,* v. 28, n. 7, July 1951, pp. 211-214. Instrument automatically records on graph paper the waviness of surfaces. Considered suitable for production work.

6-51. "Fretting Corrosion"—*The Allen Engineering Review,* n. 27, July 1951, pp. 2-4. Definition, indicated by reddish brown deposit resembling mill scale. Surfaces with high degree of finish are more affected than rough ones. Bibliography.

7-51. "Surface Finish Photometer"—*Journal of Scientific Instruments,* v. 28, n. 9, September 1951, pp. 289-290. This instrument, manufactured by Hilger and Watts, Ltd., London, measures photoelectrically the light diffusely reflected from a surface under test. Test specimen may be compared with standard surfaces. A measurement of degree of polish or "matness" of any surface is feasible. Objects, approximately flat, may be checked if ½-inch diameter or larger.

8-51. "A Simple Instrument for Evaluating Polished Buffed Surfaces"—G. E. Gardam; *Metal Finishing,* v. 49, April 1951, pp. 61-63. Qualitative measurement of polished or buffed surfaces with a simple instrument.

9-51. "Assessing Surface Texture"—*Engineering,* v. 171, April 6, 1951, p. 409. Discussion of *British Standard* 1134-1950, "The Assessment of Surface Texture."

1950

1-50. "Evaluating Casting Finishes"—H. H. Fairfield and J. MacConachie; *American Foundryman,* v. 17, n. 2, February 1950, pp. 47-48. Importance of finish stressed; graph of 25 profile measurements of cast surface made with needle-tipped dial indicator, presented with tables showing how to calculate probable maximum depth of valleys and average height of hill for aluminum, brass, iron and steel; degree of smoothness depends upon metal type. (EI)

2-50. "The Assessment of Surface Texture Centre Line—Average Height Method"—*British Standard* 1134-1950, British Standards Institution, London. Standard provides: (1) a defined basis for a simple numerical assessment of texture or roughness of a surface under conditions which ensure consistency between different instruments; (2) series of recommendations which help prevent conflicting practices in use of terms and symbols. Contents include definitions, terms, measuring instruments, standard sampling length and wave length cut-offs, British standard index numbers, standard grades of surface texture, surface texture symbols, remarks on surface profiles, determination of C. L. A. index numbers, notes on direction of measurement, notes on instrumentation, analysis of surface texture, choice of sampling lengths and alternative assessments of surface texture.

3-50. "Permanent Gloss Standards"—*Illuminating Engineering,* v. 45, n. 2, February 1950, p. 101. Data on Bureau of Standards plaques covering entire gloss range of nonmetallic commercial materials; standards may be used to calibrate any 60 degrees specular glossmeter from matte to high gloss; set consists of two white Vitrolite plaques having nominal gloss values 1 and 90, and eight intermediate glazed ceramic plaques. From *U. S. Bureau of Standards Technical News Bulletin,* October 1949. (EI)

4-50. "New Yardstick Accurately Gages Surface Finish"—*Modern Industry,* v. 19, January 1950, pp. 99-100. (IAI)

5-50. "An Electro-Deposited Surface Roughness Standard"—P. M. Aitchison; *Australian Journal of Applied Science,* v. 1, March 1950, pp. 71-74. Standard consists of a lapped steel block on which are deposited thin strips of specified width, spacing and height. This provides a known surface for use in calibration of stylus type surface finish measuring instruments. (ASM)

6-50. "On Determination of Roughness of Metallic Surfaces"—C. Wagner; *Electrochemical Society Journal,* v. 97, n. 3, March 1950, pp. 71-74. Experiments described show applicability of ballistic galvanometer to determine polarization capacities of electrodes. Measurements made in connection with development of electrolytic integrimeter, described by T. M. Moore (See *Engineering Index,* 1946, p. 988, under "Rocket Propulsion." (It can be shown that ultimate accuracy of integrimeter is determined by magnitude of polarization capacity of silver electrode used therein. Bibliography. (EI)

7-50. "Photography of Surface"—*Engineering Inspection,* v. 14, n. 1, Spring 1950, pp. 39-41. Use of photography in connection with surface measurement, particularly in testing and recording of superfinished surfaces; photography as related to nature of blemishes to which such surfaces are subject; application of photography to measurement of crystal faces of diamond and other gems, or in checking grinding of razor blades. (EI)

8-50. "Contour and Profile Investigation, Part 1"—*Aircraft Production,* v. 12, May 1950, pp. 161-166. Inspection of gas turbine components by a British firm. Includes recording of profiles on smoked glass. (ASM)

9-50. "Surface Roughness and Contact Angle"—J. J. Bikerman; *Journal of Physical and Colloid Chemistry,* v. 54, n. 5, May 1950, pp. 653-658. Contact angles and wetting as related to roughness; studies in which contact angles were measured using solid surfaces, profiles of which were determined with tracer instrument. System investigated comprised drops of distilled water in air on 18-8 stainless steel plate of different finishes; chemical composition of all plates stated to be identical. (EI)

10-50. "Measurement of Surface Smoothness"—Henry L. Kellner; *37th Annual Proceedings Technical Sessions,* American Electroplaters' Society, 1950, pp. 105-124. Instruments, methods and test data presented. Microscopic methods, microinterferometer. Brush Surface Analyzer, Profilometer, acoustical methods, replica technique, electron microscope and reflectance methods are presented. Data on tests with various instruments are given.

11-50. "A Simple Instrument for Measuring 'Surface Truth' of Metal Surfaces and the Amount of Polishing Required"—G. E. Gardam, *Journal of the Electrodepositors' Technical Society,* v. 26, 1950. Qualitative measurements can be made by visual examinations of surfaces with the instrument described.

12-50. "Contour and Profile Investigation: Part 2—Work Holding Devices, Comparator Equipment and Special Purpose Optical Apparatus for Dual Projection; Part 3—Epidiascope-type Filing Projector; Checking Fir Tree Roots"—*Aircraft Production,* v. 12, June 1950, pp. 192-197; July 1950, pp. 232-234. Techniques and equipment developed at D. Napier and Son Ltd. for inspection of gas turbine blades and similar work. (ASM)

13-50. "Measurement of Sixty-Degree Specular Gloss"—H. K. Hammond III and I. Nimeroff, *National Bureau of Standards Journal of Research,* v. 44, n. 6, June 1950 (RP2105), pp. 585-598. See also *ASTM Bulletin,* n. 169, October 1950, pp. 54-56. In order to determine uncertainties involved in calibration of gloss standards, rate of change of gloss reading with change of aperture was investigated throughout gloss scale. (EI)

14-50. "Watch Your Surface Finish, Part 1"—*Steel,* v. 126, June 19, 1950, pp. 88-90, 115-116. General discussion of terminology, costs, etc. Surface finishing measuring instruments. (ASM)

15-50. "Measurement of Surface Roughness, Part 1"—E. Green; *Finish,* v. 7, June 1950, pp. 27-30. Instruments and methods used for comparing, measuring and delineating surface profiles of metallic materials. (ASM)

16-50. "Surface Finish Control"—C. R. Lewis; *Product Engineering,* v. 21, August 1950, pp. 91-95. Problem of finish specification, new SAE standards and various effects below surfaces of metals caused by different finishing operations are discussed. Curves show test data. SAE standard; effect of finish on metal; depth of cold working; X-ray inspection; electron diffraction; stainless steel 18-8; performance of machined parts; friction coefficient; run-in of bearings; bearing lubrication; fatigue endurance; National Bureau of Standards; wear rate; protective coating.

17-50. "Surface Finish Definitions and Standards"—*Product Engineering,* v. 21, August 1950, pp. 163, 165, 167. Based on surface finish section of the new *SAE Automotive Drafting Standards.* Definition profile waviness, microinch, lay, flows, surface finish symbol. Waviness standards adopted by SAE. (ASM)

18-50. "Recording Surface Finish and Wear of Gear Teeth"—J. W. Sawyer and J. G. McCubbin, *Machinery,* v. 56, n. 12, August 1950, pp. 135-142. Comparison of various methods employed for studying roughness and progressive wear of gear teeth is presented; inspecting finish by comparison with standards; pliable film method of producing record of surface of gear teeth; rigid casting methods of producing replicas of gear teeth. (EI)

19-50. "Methods of Measurement and Definition of Surfaces"—H. Becker; *Microtechnic* (English Edition), v. 4, July-August 1950 (translated from the German). Various optical instruments. Schematic diagrams show principles of action. (ASM)

20-50. "Effect of Micro-Roughness on the performance of Parallel Thrust Bearings"—M. E. Salamail; *Proceedings of the Institution of Mechanical Engineers* 163 (W. E. P. No. 59), pp. 149-158; discussion, pp. 158-161; 1950. (IAI)

21-50. "Designation of Metallic Surfaces, Part 1"—Helmet Thielsch and George Stroman; *Metal Finishing,* v. 48, n. 9, September 1950, pp. 66-70. Fundamentals of surface qualities, terms, methods, instruments and standards are discussed. Bibliography.

22-50. "Surface Testing and Its Standardization"—H. Becker, *Metall,* v. 4, September 1950, pp. 359-365. (In German). The "feeler" method of determining and recording surface roughness. German and foreign instruments and problems of standardizing surface conditions. (ASM)

23-50. "Surface Finish and the Designer"—Roy P. Trowbridge; *Product Engineering,* v. 21, September 1950, pp. 122-127. New approach to measurement, specification and application of surface control of metallic parts. Instruments, standards for various production methods, and physical properties relating to condition of metallic surface are compared and evaluated. Instruments include brush analyzer, profilometer, proficorders, interferometer (Bausch and Lomb), dark and light field microscopy, Sheffield gage, and comparascope. Taper sectioning. Geometric specimen, electroplated specimen, replicas. Methods include turning, grinding, honing, superfinishing, forging, and casting.

24-50. "Multiple-Beam Interferometry"—S. Tolansky; *Endeavour,* v. 9, October 1950, pp. 196-202. Technique and typical results. (ASM)

25-50. "Instrument Compares Surface Finishes"—*Product Engineering,* v. 21, December 1950, p. 204. Pneumatic type instrument permits comparison of surfaces with known standards. Surface 0.125-inch diameter can be checked. Instrument manufactured by Sheffield Gage Co.

1949

1-49. "Practical Application of Surface Finish"—George Schlesinger; *American Machinist,* v. 93, January 13, 1949, pp. 101-110. Results of shop experience with tracer type or stylus instruments from 1939 to 1948. Tests were made to determine surface quality as the criterion for tool sharpness in diamond turning, precision boring, grinding, honing, lapping, and gear cutting. Examples of analyses of gear-tooth profiles produced by available processes, finishing of pistons and liners for air compressors, diamond boring a bushing and turning railway wheels. (ASM)

2-49. "Preparation and Application of Reproducible Gloss Standards"—D. Smith and M. M. Mahoney. *Journal of the Optical Society of America,* v. 39, n. 1, January 1949, pp. 86-90. Determination of factors involved in visual evaluation of gloss; polystyrene replica technique used to prepare extremely thin films of identical surface structure; transfer of these films to any desirable surface; reproducibility in surface structure and spatial reflectance characteristics of replicas made from gloss standards. (EI)

3-49. "Interferometric Study of Metal Surfaces"—S. Tolansky; *Metal Treatment and Drop Forging,* v. 16, n. 60, Winter 1949-50, pp. 195-203. Principles and techniques of interferometry develops in author's laboratories; how interferometry may be applied to study of metal surfaces.

4-49. "Applications of the Plastic Replica Process to Surface Finish Measurement"—C. Timms and C. A. Scoles; *Plastics* (London), v. 13, January 1949, pp. 24-28, 44. Use of plastic impressions for measuring the degree of surface finish of large engineering components which are not readily accessible to the exploring probes of standard designs of surface-finish recording instruments. The process consists of taking a plastic replica, the impression thus obtained being measured directly by means of a stylus recording instrument. Typical recorder charts. (ASM)

5-49. "Surface Reflectometer for Evaluating Polished Surfaces"—E. A. Ollard; *Journal of the Electrodepositors' Technical Society,* v. 24, 1948, pp. 1-8. (Reprint.) Instrument for evaluating the polish on a flat metal surface by a single reading. It will give a quantitative comparison of different surfaces in line with the results of visual examination. Suitability for electropolished surfaces. (ASM)

6-49. "Comparison of the Most Important Methods for Surface-Finish Control"—G. Michalet; *Journees des Etats de Surface,* 1946, pp. 124-134; discussion, p. 134. Different methods and equipment used for the determination of the roughness of surface and degree of polishing. Schematic drawings of equipment; methods of their application. 17 references. (ASM)

7-49. "Taper Sectioning"—E. Rabinowicz; *Metal Industry,* v. 76, n. 5, February 3, 1950, pp. 83-86. Cutting of section at small angle to surface for study of surface finish; methods of sectioning; use of taper sectioning in study of surfaces after sliding; effect of sliding small metal hemisphere on flat surface under load illustrated. Bibliography. (EI)

8-49. "Improved Surface Finish Increases Tool Life"—Thomas Badger; *American Machinist,* v. 93, February 24, 1949, p. 86. Experimental data. Surface finish improvement from 30 to 5 microinches resulted in tool-life increases of 90 to 152 percent. (ASM).

9-49. "Methode d'etude des Granulations Visibles a la Surface des Metaux Soumis a des Deformations Plastiques"—J. Herrenguel and M. Scheidecker; *Revue de Metallurgie,* v. 46, n. 8, August 1949, pp. 537-543. Study of visible granulations on surface of metals subjected to plastic deformations; granulations by corrosion patterns and slip lines; interpretation of slip lines. (EI)

10-49. "Determining the Degree of Roughness with Aid of a Flat-Grinding Process"—H. Klemm; *Archiv fur Metallkunde,* v. 2, February 1948, pp. 46-49. The process is characterized by the fact that a plane is ground at a given angle to the surface to be investigated. The consequent enlargement of roughness depends on the angle of the "grind" to the investigated surface. (ASM)

11-49. "GM and Chrysler Researchers Produce New Roughness Gage Blocks for Machined Surfaces"—W. G. Patton; *Iron Age,* v. 163, March 17, 1949, p. 106. (IAI)

12-49. "Application of Pneumatic Method for Evaluation of the Quality of Surface Finishes" (in Russian)—M. L. Brzhezinskii; *Stanki i Instrument* (Machine Tools and Instruments), v. 20, March 1949, pp. 20-22. "Pneumatic profilograph" with automatic recording. It consists, essentially, of a hydraulic pressure regulator, a pneumatic chamber, a recording manometer, and a measuring attachment. (ASM)

13-49. "Appreciation of Various States of Surface by Method of Total Reflection"—A. DeGramont; *Microtecnic* v. 3, May-June 1949, pp. 118-120. Method consists essentially of defining ratio between "carrying surface" and total surface of metal sample; description of procedure and of "surfascope." (EI)

14-49. "The Characteristics of Machined Surfaces"—A. J. Chisholm; *Machinery* (London), v. 74, June 2, 1949, pp. 729-736. Factors affecting the roughness of cut surfaces produced by simple edge-cutting tools. Lubrication surface deformation, and residual surface stresses. (ASM)

15-49. "'Talysurf' Surface-Measuring Instruments"—*Engineering,* v. 167, n. 4349, June 3, 1949, p. 523. Instruments manufactured by Taylor, Taylor, and Hobson for determining roughness of surfaces such as bearings by traversing a sharply pointed stylus over them and then electrically amplifying its movements. (EI)

16-49. "Ueber Rauhigkeitsmessung mit dem Elektronenmikroskop"—R. Seeliger; *Zeit fuer Metallkunde,* v. 39, n. 6, June 1948, pp. 170-172. See also brief English abstract in *Engineers' Digest,* v. 10, n. 5, May 1949, p. 176. Measurement of surface roughness with electron microscopes; presentation of surfaces can be effected by thin transparent detachable layers (oxides, lacquers, quartz, or metal evaporation) deposited on surface, or by matrix technique; production of stereoscopic pictures, from which distance of corresponding points can be measured and depth measurements plotted in graph; application of "shadow casting" method to electron microscope. (IAI)

17-49. "New SAE Finish Standard Aims to Help Engineer and Shop Man"—*SAE Journal,* v. 57, July 1949, pp. 33-38. The above and its use. The standard is published in the 1949 *SAE Handbook.* (ASM)

18-49. "Technological Precision and Fineness of Machining"—(In Russian)—A. A. Matalin; *Stanki i Instrument* (Machine Tools and Equipment), v. 20, July 1949, pp. 19-22. Analyzes surface-finish standards used by the Bureau of Standards and the USSR Classification according to this standard and its relation to different types of material and methods of machining. (ASM)

19-49. "A New Method for Surface Reproduction"—K. B. Mather; *Metal Progress,* v. 56, August 1949, pp. 225-227. If a reasonably flat metal surface is pressed into a fine-grained photographic emulsion at about 15,000 psi, and the plate developed and examined under a microscope, a pattern is found that reproduces the surface contours. A pronounced three-dimensional appearance results. If standardized, it is believed that the method might give a quantitative measure of surface roughness. (ASM)

20-49. "Der Stand der Normung der Oberflaechenpruefung in Deutschland, USA und England"—J. Perthen; *Werkstattstechnik u Maschinenbau,* v. 39, n. 8, 1949, pp. 252-253. Review of status of standardization of surface testing in Germany, United States and England. (EI)

21-49. "Surface Finish Requirements in Design" (abstract)—J. A. Broadston. *Mechanical Engineering,* v. 71, September 1949, p. 755. (IAI)

22-49. "Untersuchungen am Zeiss-Lichschmittgeraet nach Schmaltz"—H. von Weingraber; *Werkstattstechnik u Maschinenbau,* v. 39, n. 9, 1949, pp. 268-274. Report of investigations with Schmaltz-Zeiss microscope for precision surface testing. (EI)

23-49. "New Surface Measuring Instrument"—H. Benning-Hoff; *Industrial Diamond Review,* v. 9, n. 106, September 1949, pp. 261-262. Tracer point instrument developed in Germany by Forster during war; surfaces of 100 mm width can be tested with error of less than $\pm$ 0.2 micron; device is provided with interchangeable measuring tubes; testing limits are 100 microns and 0.1 micron. English translation from *Archiv fuer Oberflaechentechnik.* (EI)

24-49. "Effect of Surface Roughness on Rolling Friction"—J. J. Bikerman, *Journal of Applied Physics,* v. 20, n. 10, October 1949, pp. 971-975. Minimum tilt at which bearing balls roll down inclined plate of stainless steel is greater for rough than for smooth surfaces. Roughest surfaces gave almost quantitative agreement between height of elevations and height of hills calculated from theory attributing rolling friction to surface roughness; surface roughness seems to cause rolling friction at low pressures. (EI)

25-49. "Examination of Surfaces"—J. W. Sawyer, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, v. 61, n. 4, November 1949, pp. 819-827. Permanent and accurate three-dimensional records of surface finish and damage can be made. Record made by casting onto surface a resin which hardens in about 20 minutes after addition of catalyst; resin and catalyst are preweighed and packaged ready for immediate use. External heat and pressure not required. After resin hardens casting is removed for study; negative replica may be tested with profilometer or similar surface measuring instrument without damage to casting. (EI)

26-49. "A New Concept of Surface Measurement. Present Methods of Surface Finish Control and Development of Geometric Surface Finish Standards"—Arthur F. Underwood and Roy P. Trowbridge. Development of ruled surface-finish standard by General Motors Corp. Originals are made on 2- by 3-inch blocks of silver-

clad steel plates with gold. The surface is polished to an average roughness of one microinch. Rulings are made on a special machine with a diamond stylus. Duplicates are made by an electroforming process. Method of calibration and use of Nelson's taper sectioning method which increases magnification in one direction by as much as 25 to 1. (ASM)

27-49. "Surface Roughness of Metals"—T. P. May and R. L. Burrell, Jr., *Steel*, v. 125, November 21, 1949, p. 118. Abstract of paper on gas adsorption method for determining roughness of metal surfaces. (IAI)

28-49. "Calibration and use of Master Roughness Standards"—C. R. Lewis; *The Tool Engineer*, v. 23, November 1949, pp. 22-24. (IAI)

29-49. *Prufefen und Messen der Oberflaechengestalt*—J. Perthen, Carl Hanser Verlag, Munich, Germany, 1949, 257 pages. Volume three of series on technical measurements deals with surface conditions, with methods and apparatus for testing and measuring surfaces, with practical application of surface measurement and its relation to interchangeable manufacturing. Bibliography. Engineering Societies Library, New York. (EI)

1948

1-48. "Plastic Replicas for Surface-Finish Measurement"—J. Pearson and M. R. Hopkins; *Journal of the Iron and Steel Institute*, v. 158, January 1948, p. 138. The methods hitherto described are said to be unsuitable for roughness measurements by stylus instruments. The technique outlined is of more general applicability, as it requires no heating and can be used to make negative surface replicas from objects of any size, roughness, or location. (ASM)

2-48. "Roughness of Surfaces"—W. A. Tuplin; *British Science News*, v. 1, 1948, pp. 18-20. Measuring the roughness of surfaces by use of a stylus which traverses the work. (ASM)

3-48. "American Standard on Surface Roughness" (symposium of three articles); "Why Surface Roughness Standard?"—R. F. Gagg; "What Standard on Surface Roughness Covers"—E. R. Boynton; "One Company's Analysis of Why and How to Use Surface Roughness Standard"—J. W. Owens; *Industrial Standardization*, v. 19, n. 1, part 1, January-February 1948, pp. 6-13. Symposium of three articles on American Standard B46.1-1947, *Surface Roughness, Waviness and Lay*. (EI)

4-48. "Report of Committee on Standards for Machined Surface Finishes"—Hugh B. Conover; *Iron and Steel Engineer*, v. 25, February 1948, pp. 62-63, 65. Includes AISE Standard No. 3. (ASM)

5-48. "Surface Finish"—F. C. Johansen; *Journal of the India Society of Engineers*, v. 13, Feb. 1948, p. 36-40; April 1948, p. 75-80. First installment; methods used to obtain polished or smooth surfaces such as milling, grinding, lapping, electrolytic polishing; methods for determining the conditions of surfaces. Second installment: the various types of surface-finish meters and the physical effects of surface conditions. (ASM)

6-48. "Surface Analysis with Plastic Replicas"—A. J. Chisholm and J. M. Lickley; *Engineering*, v. 165, April 23, 1948, p. 389. (IAI)

7-48. "Proficorder—Instrument for Recording Waviness and Other Surface Profiles"—E. J. Abbott and E. Rupke; *Transactions of the American Society of Mechanical Engineers,* v. 70, n. 4, May 1948, pp. 263-269; Discussion, 269-270. Function of instrument described is to reproduce with appropriate magnifications, actual profile of considerable length of surface; it permits study of individual irregularities as to size, shape, and relative position with respect to other irregularities; instrument can be used to good advantage for inspection of production; setups for waves and other surface characteristics for study of surface finish. (EI)

8-48. Wear and Surface Finish—E. L. Hemingway; Gisholt Machine Co., Madison, Wis., 80 pages. The measurement of surface finish, methods of finishing, the reasons for wear and its relation to desirable finish. (From review in *American Machinist,* v. 92, May 6, 1948). (ASM)

9-48. "Plastic Replicas for Surface-Finish Measurement"—J. Pearson and M. R. Hopkins; *Journal of the Iron and Steel Institute,* v. 159, May 1948, pp. 67-70. Methods for producing plastic replicas presented.

10-48. "High Precision Surface Finish Standard to be Offered Metal Processing Industry"—Clayton R. Lewis and Arthur F. Underwood; *Steel,* v. 123, July 19, 1948, pp. 90-92, 124. How the problem of making a master set of standard surface-finish specimens was solved after two years' study by General Motors and Chrysler engineers. Newly designed fine-line ruling machine will rule grooves in a polished specimen up to 10,000 lines per inch while holding pitch accurate to $\pm$ 2 percent. (ASM)

11-48. "Measuring Roughness With the Electron Microscope"—Robert Seeliger; *Zeitschrift fur Metallkunde,* v. 39, June 1948, pp. 170-172. Method and its basic principles. Irregularities of 100 micron or less can be accurately measured. (ASM)

12-48. "O.P.L. Direct-Vision Surfascope"—*Engineers' Digest* (British Edition), v. 9, n. 7, July 1948, p. 239. Illustrated description of instrument developed by Society d'Optique et Precision of Levallois, for measurement of surface roughness of metal specimens; based on "extinguished total reflection" method, suggested by Golliet, Grunwald and Levy. English abstract from *Measures and Control Industriel,* v. 13, n. 130, March 1948, pp. 99-101. (EI)

13-48. "Recent Developments in Surface Measurement"—Allen G. Gray; *Products Finishing,* v. 12, August 1948, pp. 70, 72, 74, 76, 78, 80. Methods and equipment for measuring surface roughness.

14-48. "How to Specify Surface Quality"—J. F. Fischer; *Machinery,* v. 55, n. 1, September 1948, pp. 174-177. Definition of geometrical irregularities of surfaces, as set forth in American Standard B46.1-1947; recommended method of indicating surface specifications on drawings; typical surface finish samples currently used; method of securing comparison between surfaces; importance of grinding and cutting tool conditions and their effect on qualities obtained. (EI)

15-48. "Optische Betrachtungen zum Litchschnitternitt-verfahren fuel die Oberflaechenpruefung"—K. Raentsch; *Werkstattstechnik and Werksleiter,* v. 35, n. 18, September 15, 1941, pp. 309-313. Optical aspects of microscopic light slit method of surface testing, developed by G. Schmaltz; its principle, applications and advantages; diagram; tables and photomicrographs. (EI)

16-48. "How Smooth is Smooth? Specification and Evaluation of Machined Finishes"—Ben C. Brosheer; *American Machinist,* v. 92, September 9, 1948, pp. 97-112; September 23, 1948, pp. 111-122. Details of various methods for the above and of the different standard specifications, specimen blocks, and measuring and inspection equipment. Part 2 deals with optical comparators. 113 references. (ASM)

17-48. "The New American Standard on Surface Finish"—George Schlesinger; *Machinery Lloyd* (Overseas Edition), v. 20, September 25, 1948, pp. 91-95. (ASM)

18-48. "The Determination of Flatness of Surfaces and Straightedges; Methods and Instruments Developed at the Rochdale Technical School"—*Machinery* (London), v. 73, September 30, 1948, pp. 497-500. (ASM)

19-48. "Control of the Quality of Surfaces by a Printing Method" (In Russian) —N. M. Ziuskin; v. 13, September 1947, pp. 1143-1145. A system for photographing flaws and irregularities in surfaces, especially in cramped locations, such as inside gun barrels. (ASM)

20-48. "Permissible Limits and Measurement of Roughness of Machined Surfaces"—P. E. Dyachenko; *Engineers' Digest* (British Edition), v. 9, n. 10, October 1948, pp. 340-342. See also *Engineers' Digest* (American Edition), v. 5, n. 8, October 1948, pp. 385-387. When cutting speed and rate of longitudinal feed are changed there is range in which roughness caused by cutting edge changes rapidly; diagrams show limits of various ranges in which roughness characteristics differ from each other. Formulas for determining roughness also given. English abstract from *Stanki i Instrument,* n. 9, 1947, pp. 17-20. (EI)

21-48. "Contemporary Feeler Equipment for Quantitative Determination of Surface Roughness"—P. E. Dyachenko; (In Russian); *Bulletin of the Academy of Sciences of the USSR, Section of Technical Sciences,* October 1948, pp. 1627-1633. Existing methods and apparatus. Comparative results. (ASM)

22-48. "Control of Surface Finish Improves Quality, Cuts Cost"—H. R. Clauser; *Materials and Methods,* v. 28, October 1948, pp. 74-77. Significance of roughness, waviness, and lay or scratch pattern and methods for their measurement. How surface-finish control improves quality and cuts costs. (ASM)

23-48. "Seek Way to Control Surface Finish Quality," based on "The Present Status of Surface Finish Control"—C. R. Lewis; *SAE Journal,* v. 56, October 1948, pp. 92-93. Problems involved in establishment of criteria of surface-finish quality, including both roughness and character, and in development of standards providing a common reference point for work in this field. (ASM)

24-48. "Controlling Surface Finish to Specified Quality Standards"—Roger F. Waindle; *Tool and Die Journal,* v. 14, October 1948, pp. 66-70. Methods used by Elgin National Watch Co. (ASM)

25-48. "Some Applications of Plastic Replica Process to Surface Finish Measurement"—C. Timms and C. A. Scoles; *Machinery,* (London), v. 73, n. 1887, December 23, 1948, pp. 871-875. Suitability of technique for measurement of finish of large engineering components, such as marine gear teeth and flanks of master lead screws, which are not readily accessible with standard instruments; plastics replica of machined surface is made on strip or film of cellulose acetate, impression thus obtained being measured directly by means of stylus recording instrument; application to flat and curved surfaces; accuracy discussed. (EI)

26-48. "Designating Surface Roughness with Aid of Geometric Standards"—C. R. Lewis and A. F. Underwood; *Machine Design,* v. 20, n. 12, December 1948, pp. 137-140. General Motors Corp. and Chrysler Corp. Project which involved production of master set of standard surface finish specimens from which exact replicas could be made; final plan entailed making master specimens by ruling geometric pattern on flat polished gold plates with diamond stylus. Manner of making replicas proposed surface finish standard; symbols and surface finish specifications; definitions used. (EI)

27-48. "Refined Surface Finishes"—W. Johnson; *Iron and Coal Trades Review,* v. 157, n. 4216, December 31, 1948, pp. 1485-1487. Interpretation of surface roughness readings; some of methods, processes, and equipment used to produce superfine finishes; description of effect of surface roughness readings on performance of journal bearings also dealt with; special reference to various components in steel plant equipment. Before International Congress of Mechanical Engineering, Paris, September 1948. (EI)

1947

1-47. "Control and Measurement of Surface Finishes"—J. A. Broadston; *Steel,* v. 120, n. 2, January 13, 1947, pp. 82-83, 116, 118, 121. See also *Iron Age,* v. 159, n. 12, March 20, 1947, pp. 51-55 and *American Machinist,* v. 91, n. 8, April 10, 1947, pp. 102-103. Recommended principles and procedures regarding selection and utilization of existing instrumentation in controlling surface quality of products whose performance depends upon proper surface finish, and for future improvement of surface finish measurement instrumentation; emphasis on present need for universal reference standard for finishes to control surface quality of machined parts on production line. (EI)

2-47. "Structure des Surfaces Polies"—H. Raether; *Metaux et Corrosion,* v. 22, n. 257, January 1947, pp. 2-17. Structure of mechanically or electrolytically polished surfaces; review of different methods of surface examination. It is shown how, by means of electrons, fine structure of surfaces can be penetrated, and that combined use of electron diffraction and electron microscope is important contribution to study of surface structure. (EI)

3-47. "The Structure and Appearance of Metal Surfaces"—J. H. Nelson; *Metal Treatment,* v. 13, Winter 1946-1947, pp. 279-285. Effect of surface defects of various magnitudes on the surface appearance of metallic objects. Particular attention to the process of "superfinishing." (ASM)

4-47. "Evaluates Finishes"—*Steel,* v. 120, March 17, 1947, p. 112. Evaluation of surface finish or roughness is obtained by a new National Bureau of Standards method in which a carefully prepared plastic replica of the surface is analyzed by photoelectric means. Replica is produced by applying a suitable solvent to the test surface and pressing on a strip of clean plastic film. When dry, the film is readily stripped from the surface. (ASM)

5-47. "Practical Aspects of Surface Finish Measurement Instrumentation"—James A. Broadston; *Iron Age,* v. 159, March 20, 1947, pp. 51-56. Practical application of surface finish control. Development of finish control and instruments available for measuring surface finish in the plant. Effectiveness, costs and methods of using various types of finish control devices. (EI)

6-47. "Requirements in Surface Finish"—D. McConnell; *Journal and Proceedings of the Institute of Mechanical Engineers,* v. 153, 1945 (War Emergency Issue No. 10), pp. 341-342; Same, *Engineering,* v. 159, March 23, 1945, p. 238. (IAI)

7-47. "Superfinishing Methods and Applications, Part I"—E. L. Hemingway; *Machinery,* v. 53, March 1947, pp. 154-158, 174. Details of the superfinishing process and methods of applying it to flat and cylindrical parts. (ASM)

8-47. "Surface Roughness, Waviness, and Lay, Part I"—American Standards Association; American Standard B46.1-1947, 7 pages. Sponsors: Society of Automotive Engineers and American Society of Mechanical Engineers. Standard is concerned with geometrical irregularities of surfaces of solid materials; definite classifications established for various degree of roughness and waviness, and for several varieties of lay; set of symbols provided for use on drawings, and in specifications, reports, etc. (EI)

9-47. "Effect of Surface Finish on Fatigue Limit of Mild Steel"—J. S. Caswell; *Product Engineering,* v. 18, March 1947, p. 152. Investigations on the effect of surface scratches in the direction of and transverse to the principal stress direction. Fatigue tests were carried out on mild steel specimens ground and polished in a circumferential direction, and also on other specimens, which were ground and polished in a longitudinal direction. Probable stress distribution along a diameter for specimens ground and polished in the two ways. (ASM)

10-47. "Surface Roughness, Waviness and Lay, Part I"—*American Machinist,* v. 91, April 10, 1947, p. 155. Standard is concerned with the geometrical irregularities of surfaces of solid materials. Establishes definite classifications for various degrees of roughness and waviness, and for various varieties of lay. It deals only with their height, width, and direction. (ASM)

11-47. "Surface Finish Measurement Instrumentation"—James A. Broadston; *Instruments,* v. 20, April 1947, pp. 374-377. Advantages for production of metal parts and equipment. (ASM)

12-47. "Surface Quality Control Does Pay"—J. A. Broadston; *American Machinist,* v. 91, April 10, 1947, pp. 102-103. (IAI)

13-47. "Superfinishing Methods and Applications, Part II"—E. L. Hemingway; *Machinery,* v. 53, April 1947, pp. 168-171. Typical applications of the superfinishing process on bearings and shop tools, and for inspection work. (ASM)

14-47. "New Replica Techniques for Evaluating Engine Wear"—*Automotive and Aviation Industries,* v. 96, n. 8, April 15, 1947, pp. 36-37, 78. Two methods of evaluating surface finishes of engine parts subject to wear; National Bureau of Standards process developed by H. K. Herschman is based on use of plastic replica which reproduces in minute detail protuberances and recesses of surface, and photoelectric means of evaluation. Process developed by NACA Aircraft Engine Research Laboratory; also uses plastic replica, but examination is made by microscope. (EI)

15-47. "Optical Methods for Evaluation of Metal Surfaces"—A. A. Vernon and J. Broomfield; *Metal Finishing,* v. 45, n. 4, April 1947, pp. 70-71. Classification and principles of available instruments; discussion of those showing picture of surface and one which measures light reflected from surface; surface pictures for comparative evaluation; dual microscope for visual comparison; quick scanning surface comparator operating on reflection principle. Bibliography. (EI)

16-47. "Surface Analyzer for Estimation of Roughness"—M. M. Tennenbaum; *Factory Laboratory* (U.S.S.R.), v. 13, May 1947, pp. 635-637. (In Russian). Motion of a needle point over the surface of the specimen is amplified by two piezo-elements and recorded graphically by a moving pen. Curves produced by the instrument and true surface profiles are presented in pairs for several types of surfaces. Reason for differences is explained on the basis of the finite dimensions for the needle point. (ASM)

17-47. "Tracer-Point Sharpness as Affecting Roughness Measurements"—D. E. Williamson; *Transactions of the American Society of Mechanical Engineers,* v. 69, May 1947, pp. 319-323. Test procedure proposed to show the differences in average roughness readings that are obtained on a variety of specimens using tracer points of different sharpness. Four diamond points were obtained in mounts to suit them for use in the common type of profilometer tracer. Measurement of average roughness on metal surfaces finished with abrasives can be satisfactorily carried out by tracer-point methods. Regardless of the smoothness of the piece, a tip radius of 0.0005-inch is adequate. (ASM)

18-47. "David Brown and Sons Topograph Surface Recorder"—*Engineer,* v. 183, May 9, 1947. (IAI)

19-47. "Surface Finish Measurement Instrumentation"—James A. Broadston; *Instruments,* v. 20, June 1947, pp. 570-572. Requirements and problems involved. (ASM)

20-47. "Smooth Surfaces Increase Plain-Bearing Capacity"—E. L. Hemingway; *American Machinist,* v. 91, n. 12, June 5, 1947, pp. 92-95. Results of tests to study effects of rough and wavy surfaces and dimensional or geometrical inaccuracy of bushings and shafts on load-carrying capacity and life of plain bearings. Tests with recording wattmeter show smooth surfaces will carry heavier loads, run cooler, can be fitted to closer tolerances, and suffer much less wear. (EI)

21-47. "Measuring Millionths with New British Surface Measuring Instrument; Topograph"—*Steel,* v. 120, June 2, 1947, p. 114. (IAI)

22-47. "New Replica Techniques for Evaluating Engine Wear; Surface Finishes Reproduced in Plastic"—*Automotive and Aviation Industry,* v. 96, April 15, 1947, pp. 36-37. Excerpt. *Product Engineering,* v. 18, June 1947, p. 146. (IAI)

23-47. "How to Measure Surface Roughness of Castings"—G. Hobman; *American Machinist,* v. 91, n. 14, July 3, 1947, pp. 94-95. Details of Hobman-Meehanite surface meter—direct reading, portable instrument of stylus type. Readings of ordinates are taken at 0.01-inch increments and recorded graphically. Included is list of required classifications covering all normal ranges of surface roughness presently encountered. (EI)

24-47. "Measures Contours of Surfaces"—F. R. Nitchie, Jr.; *Machine Design,* v. 19, July 1947, p. 136. Mechanical instrument developed to measure the dimensions of marine propellers to tolerances much smaller than those generally accepted. This instrument should prove useful for any application requiring the measurement of radial or concentric cylindrical contours or sections, particularly of irregular surfaces. (ASM)

25-47. "Unusual Applications of Superfinishing"—E. L. Hemingway; *Machinery* (London), v. 71, August 7, 1947, pp. 156-157. Superfinishing of reamers and punches to improve results and life; of steam-valve disks and seats to reduce steam leakage; of pump piston-rods to eliminate the rasp effect between the rod

and the nonmetallic packing; of gun recoil pistons to improve performance of aircraft engine parts to stop scoring; and of diesel engine crankshafts and automobile tappet valves to improve smoothess where they contact mating parts. Inspection of metal surfaces. (ASM)

26-47. "Testing of Flatness by Bean Comparator Method"—R. Marrinar and W. O. Jennings; *Engineer,* v. 184, n. 4778, August 22, 1947, pp. 164-165. Method described was devised at National Physical Laboratory and used for testing quickly and with reasonable accuracy large batches of surface plates of same size; it is particularly convenient for testing flatness of surfaces during manufacture. Principle is that of comparing, by means of sensitive dial indicator, straightness of succession of generators in surface under test with that of known reference straightedge. (EI)

27-47. "Determining Surface Roughness"—W. Mikelson; *Mechanical Engineering,* v. 69, n. 5, May 1947, pp. 391-393; see also *Mechanical World,* v. 122, n. 3162, August 22, 1947, pp. 199-200; *Engineers' Digest* (British Edition), v. 8, n. 9, September 1947, pp. 293-294. Use of new standard surface roughness specimens, depicting 10 degrees of roughness with total of 25 different finishes; set consists of 10 metal blocks; each 2 x 2½ inch, each identified by letter and representing certain degrees of roughness; several are subdivided into two or four different surfaces to show finishes of same degree of roughness, but made by different types of machines. (EI)

28-47. "Analysis of Surface Quality of Zinc-Base Die Castings"—A. W. Sundwick; *Steel,* v. 121, September 15, 1947, pp. 94-95. Same abr. *American Machinist,* v. 91, September 25, 1947, pp. 127, 129, 131. (IAI)

29-47. "Mobile Laboratory Measures Surface Finish in Shop"—A. A. Goodman; *American Machinist,* v. 91, n. 22, October 23, 1947, pp. 104-105. Features of small analyzer installed at Steam Div., Westinghouse Electric Corp. Standard complement carried in mobile unit consists of type "Q" profilometer and type "V" Motorace for machine controlled operation of various profilometer tracing heads. (EI)

30-47. "Fine Finishes and Flatness Obtained by Surface Grinding"—*Machinery,* v. 54, October 1947, pp. 152-153. Production of finishes varying from 2 microinches for hardened steel to 15 microinches for aluminum. (ASM)

31-47. "Surface Hardness Comparator"—*Industrial Diamond Review,* v. 7, October 1947, p. 298. British-made comparator consists of a plastic holder with nine projecting steel pins of different hardnesses. To determine surface hardness, adjacent pins are rubbed across the surface to be tested until one pin scratches the surface, whereas the other slides. (ASM)

32-47. "Finishing with Diamond Tools"—Paul Grodzinski; *Machine and Tool Blue Book,* v. 43, October 1947, pp. 174, 176, 178, 180. Finishing parts to one microinch with diamond single-point tools. (ASM)

33-47. "Surface Roughness Measured by Resistance to Air Flow; Rugosimeter" —*Product Engineering,* v. 18, November 1947, pp. 100-101. (IAI)

34-47. "Modern Mechanical Surface Finishing"—Martin Manier; *Metal Finishing,* v. 45, November 1947, pp. 62-66. A review of equipment, procedures and materials. 17 references. (ASM)

35-47. "Dry Friction of Metals as Affected by Surface Finish and Surface Coatings"—N. Ludwig; *Engineers' Digest* (American Edition), v. 4, November 1947, pp. 516-517. Apparatus for measuring sliding frictional resistance by use of a test cube pressed against a plane surface. Effect of surface finish was determined for four metals or alloy and for four grades of mechanical smoothness—rough, machined; fine machined; ground; and polished. The frictional resistance of ten different surface coatings of either phosphated or plated types was also determined. (Translated and condensed from *Die Technik,* v. 2, April 1947, pp. 166-170). (ASM)

36-47. "Surface Finish Measurement of Engineering Components"—C. Timms; *Journal of the Institution of Production Engineers,* v. 26, n. 12, December 1947, pp. 411-426. Measurement and analysis of surface irregularities of materials; results of research program of National Physics Laboratory in England; stylus types of instrument capable of recording to high scale of magnification surface irregularities which hitherto have been assessed by practical workshop methods such as fingernail test; other instruments. (EI)

1946

1-46. "Checking surface finish; Comparoscope"—*Steel,* v. 118, January 28, 1946, p. 115. (IAI)

2-46. "Surface Finish of Reduction Gear Teeth"—J. A. Davies; *Journal of the American Society of Navy Engineers,* v. 58, February 1946, pp. 16-20. Use of Faxfilms for inspection of gear tooth surfaces. Process can be and has been used on any surface the condition of which is subject to question. (ASM)

3-46. "Optical Methods for the Examination of Surfaces"—B. Firschmuth. *Industrial Diamond Review,* v. 6, March 1946, pp. 70-74. Optical methods used at present for the examination of surface finish, particularly the Schmaltz "light-slit" method. Adapter is described which enables method to be carried out with the aid of a standard inverted type metallurgical microscope. Usefulness of adapter is illustrated in a number of photomicrographs obtained with various types of surfaces. (Translated from *Schweizer Archiv fuer angew, Wissenschaft and Technik,* v. 11, September 1946, pp. 262-269.) (ASM)

4-46. "Surface Finish; what surface profile is really like, as shown by ordinary and electron microscopes"—L. H. Milligan; *Diesel Power,* v. 24, March 1946, pp. 336-338. (IAI)

5-46. "Determination of Surface Roughness by Use of Longitudinal Feelers and by Interference Techniques"—F. Flamant and M. A. Arnulf; *Journees des Etats de Surface,* 1946, pp. 110-116; discussion, p. 116. Application of individual methods to different surfaces, after simple machining, grinding, mechanical or electrolytic polishing. (ASM)

6-46. "A Glossmeter for Smoothness Comparisons of Machine-Finished Surfaces"—Richard S. Hunter; *Journal of the Optical Society of America,* v. 36, March 1946, pp. 178-181. Since shininess is one indication of surface smoothness, a photoelectric glossmeter was developed for possible use as a production-inspection device for determining the roughness of machine-finished surfaces between 100 and 500 microinches root mean square deviation from mean surface. (ASM)

7-46. "Putting a Glassy, Smooth Finish on the Shooting Star"—Fred M. Burt; *Industrial Finishing,* v. 22, March 1946, pp. 27-32. New materials and technique used to condition all metal surfaces. Gives 11 important steps in superfinishing schedule. (ASM)

8-46. "Conference on Surface Finish"—*Journal and Proceedings of the Institution of Mechanical Engineers,* v. 153 (War Emergency Issue No. 10), pp. 331-351. *Engineering,* v. 159, March 16-April 13, 1945, pp. 215-220, 237-239, 258-260, 277-280, 299; same, condensed in *Engineer,* v. 179, March 16-30, 1945, pp. 218-220, 230-231, 250-251. Discussion; *Journal and Proceedings of the Institution of Mechanical Engineers,* v. 153 (War Emergency Issue No. 10), pp. 352-379; *Engineer,* v. 179, March 16-23, 1945, pp. 209-211, 234-236. (IAI)

9-46. "Polissage Electrolytique et Superfinition"—R. Mondon; *Technique Moderne,* v. 38, n. 23-24, December 1-15, 1946, pp. 281-286, v. 39, n. 1-2, January 1-15, 1947, pp. 17-21. Electrolytic polishing and superfinishing; various types of finishing; application of profilometer to surface testing influence of electrolytic polishing on mechanical properties; application to detection of surface defects. (ASM)

10-46. "Measurement of Surface Roughness"—C. J. Posey, *Mechanical Engineering,* v. 68, n. 4, April 1946, pp. 305-306, 338; see also *Mechanical World,* v. 119, n. 3102, June 14, 1946, pp. 672-674. Regarding types of equipment used to measure surface roughness, paper mentions differences in British and American practices and points out that neither takes into account all factors involved; difficulty of defining concept of identical or similar surface roughness; use of histogram method of analysis by means of which depth, slope and curvature distribution characterizes profile roughness completely. (EI)

11-46. "Comparison of Roughness of Super-Finished Plane Surfaces"—J. Kluge and G. Bauchmann; *Product Engineering,* v. 17, May 1946, pp. 401-402. Foreign abstract. Instrument employing photoelectric cell developed to give qualitative measurement of surface roughness. Test compared with those of Schmaltz surface tester.

12-46. "The Surface Condition and Reflectivity of Metals"—J. H. Nelson; *Journal of the Electrodepositors' Technical Society,* v. 21, 1946, pp. 113-120 (Reprint). Theories of surface reflectivity are outlined. Superfinishing technique and method for comparison of finish smoothness are described. Application of reflectivity as a tool in razor blade inspection is explained. (ASM)

13-46. "Measurement of Surface Roughness"—C. Timms, *Metal Treatment,* v. 13, n. 46 (Summer), 1946, pp. 111-118. Optical surface recording instruments developed for this purpose; range of roughness accommodated by each; difficulties to be overcome in order to establish rational specification for surface roughness and present progress; need for correlation between physical and geometrical aspects of suface to determine important surface qualities. Before Paris Congress, Organized by La Commission Technique des Etats et Proprietes de Surface des Metaux. (IAI)

14-46. "Les Etats de Surface"—Lasnier and Plagnol; *Journal des Societe des Ingenieurs de L'Automobile,* v. 18, n. 4, July-August 1945, pp. 117-130. Present knowledge of surfaces; definition; examination with mechanical and optical apparatus, electron microscope, electrical and other methods; study of behavior of surfaces. (EI)

15-46. "Measuring Surface Roughness"—*Product Engineering,* v. 17, n. 8, August 1946, p. 117. New method and apparatus for surface inspection; equipment consists basically of microscope with adjustable lighting shutter, translucent intermediate bender; and light concentrating lamp; application described. English abstract of article from *VDI Zeit,* February 20, 1945. (IAI)

16-46. "L'etat des surfaces metalliques"—P. Bastien and C. de Senneville; *Technique Moderne,* v. 38, n. 15, 16, 19, 20, August 1, 15, 1946, pp. 169-176; October 1, 15, pp. 223-228. State of metal surfaces. August: Physical and physical chemical state; methods of studying constitution and structure. October: Study of shape of surfaces; macro and micro roughness; influence of surface state on friction, electric conductivity, hardness, fatigue and corrosion. (IAI)

17-46. "Replica Method for Roughness Measurement"—H. Smoluchowski; *Review of Scientific Instruments,* v. 17, August 1946, p. 309. Simple method which shows type of roughness, and can be used in hard-to-get-at places. Cellulose acetate dissolved in acetone is applied. Before it dries, cellulose acetate tape is pressed on. When it is pulled off, the botom is covered with an accurate replica of the surface. In a variation of technique, dye is added to the solution, so that the replica may be exposed to a light beam for quantitative roughness determination with a photo-cell. (ASM)

18-46. "Standard Classification of Machined Surface Finish"—P. E. Dyachenko; *Engineers' Digest* (British Edition), v. 7, n. 9, September 1946, p. 297. Account of USSR standard classification of microsmoothness of surfaces based on root mean square value of deviation as measured on Abbott type surface measuring instrument; standard curve of equivalents given to permit translating this in terms of maximum deviation, should this other criterion be necessary. Brief English abstract from *Vestnik Inzhenerov I tekhnikov,* Russia, n. 2, 1946, pp. 73-78. (EI)

19-46. "A New Approach in Evaluating Surface Roughness of Gear Teeth"—L. D. Martin; *Product Engineering,* v. 17, September 1946, pp. 110-114. Standard for comparing surface roughness of gear teeth by visual inspection.

20-46. "Suggestions Concerning Use of Correlation Charts for Interpretation of Surface-Finish Records"—J. R. Womersley and M. R. Hopkins; *Journess des Etats de Surface,* 1946, pp. 135-139; discussion, p. 139. The profilogram obtained by an apparatus with feelers does not define completely the condition of the surface. The true surface condition may be determined only by meticulous analysis of a series of profilograms compiled into a correlation chart. (ASM)

21-46. "Precision Measurement, Section 1—Inspection Instruments, Continued; Part 3—Optical Flats"—Warren Baker. *Machine Tool Blue Book,* v. 42, September 1946, pp. 141, 142, 144, 146, 148, 150, 152, 154, 156, 158, 160, 162, 164, 166, 168, 170, 172, 174. Theory and use of optical flats; examples. (ASM)

22-46. "Interference Microscope for Testing Surfaces"—*Industrial Diamond Review,* v. 6, n. 70, September 1946, pp. 276-279. Instrument for direct measurement of profile heights on smooth surfaces for maximum roughness of 0.05 to 2 micron (2 to 80 microinches) over certain portion of workpiece surface under test; method of testing, operation and adjustment; interpretation of interference patters; design and mounting; use of photographic equipment and evaluation of pictures; calibration. (EI)

23-46. "Surface Finish in Production Methods"—W. E. R. Clay; *Institution of Mechanical Engineers Proceedings,* v. 153, 1945, War Emergency Issue No. 10, pp. 342-343. Grinding; honing; superfinishing; lapping. (Paper for Symposium on Surface Finish.) (ASM)

24-46. "Measurement of Surface Waviness"—C. Timms; *Institution of Mechanical Engineers Proceedings,* v. 153, 1945, (War Emergency Issue No. 10), pp. 337-339. A portable instrument of simple construction designed at the National Physical Laboratory for the measurement of the grosser surface irregularities. (Paper for Symposium on Surface Finish.) (ASM)

25-46. "How to Measure Surface Roughness of Castings"—G. Hobman; *American Foundryman,* v. 16, October 1946, pp. 46-47. Use of dial gage and stylus type contact point. (ASM)

26-46. "Surface Finish Measurement Instrumentation"—James A. Broadston; *Tool & Die Journal,* v. 12, October 1946, pp. 81-86, 105, 170. Various commercial instruments used. (ASM)

27-46. "Talysurf Surface Meter"—*Electronic Engineering,* v. 18, n. 225, November 1946, p. 351. Notes on stylus type of electronic instrument for measuring texture of surfaces; it provides both graph showing cross section of surface, and number representing average height of texture; suitable for measurement of all irregularities whose spacing lies in range between about 0.0002-inch and 0.1-inch; applicability to grinding, fine turning and milling; and fine finishing. (EI)

28-46. "Measurement of Surface Finish"—*Commowealth Engineering,* v. 34, n. 4, November 1, 1946, pp. 130-134. Comparison of relative merits of taper sectioning, optical methods and stylus instruments for obtaining quantitative measurement applications. Article deals particularly with results obtained and apparatus available for this purpose at Munition Supply Laboratories, Maribyrong, Victoria. (EI)

29-46. "Profile and Surface Analysis"—*Aircraft Production,* v. 8, n. 97, 98, November 1946, pp. 509-512; December 1946, pp. 557-560. November: Napier technique of checking gear teeth by combination of mechanical and optical magnification described. December: some variants of method as applied to surfaces of certain other components, including valve sleeves, are dealt with. (EI)

30-46. "Evaluating Surface Roughness of Gear Teeth"—L. D. Martin, *Iron Age,* v. 158, November 21, 1946, p. 144. (IAI)

31-46. "Blow-Up Photos Facilitate Research and Inspection"—M. W. Seavey; *Tool Engineer,* v. 17, November 1946, pp. 45-58. Photographing contour projections on optical comparator assists in the control of quality. (ASM)

32-46. "Tapering for Surface Inspection"—W. J. Darmody; *American Machinist,* v. 90, n. 26, December 19, 1946, pp. 134-135. Experiments with taper sectioning, conducted in connection with standardization of Ordnance finish blocks at Frankford Arsenal Gage Laboratory; taper sections formed by grinding and lapping of surface area to be evaluated; machining methods used to prepare block for surface inspection; lapping compounds used; utilization of two different ways of positioning light for examining surface finish under microscope. (EI)

33-46. "Comtor Surface Smoothness Comparator"—*Machinery,* v. 52, December 1945, p. 220. (IAI)

34-46. "Trentini Surface Tester"—*Industrial Diamond Review,* v. 6, December 1946, p. 375. Swiss instrument in which surface finish or roughness is measured by producing shocks in an electrical system. These shocks are produced by drawing a needle with a blunt point across the surface at constant velocity and under constant load, the magnitude of the impulses being proportional to the roughness of the measured surface. (ASM)

35-46. "Profile and Surface Analysis, Part II"—*Aircraft Production,* v. 8, December 1946, pp. 557-560. Combined mechanical and optical methods for checking by projection as applied to surfaces of certain components, including valve sleeves. (ASM)

1945

1-45. "Evaluation of the Finish of a Metal Surface by a Replica Method"—Harry K. Herschman; *National Bureau of Standards Journal of Research,* v. 34, January 1945, pp. 25-31. Method for evaluating surface finish through the medium of a nearly transparent plastic replica of a surface described. The method consists essentially in passing a narrow beam of light transversely through the moving replica onto a photoelectric cell. Variations in the geometric characteristics of the film, which are associated with the serrations of the surface reproduced, control the intensity of the light passing through the film and reaching the photocell at any instant. The fluctuations of intensity of the transmitted light cause a pulsating voltage in the cell circuit, which is recorded by an electronic voltmeter. This voltage increases with increased surface roughness. The evaluations obtained by this means are very promising. Results for different surface finishes are correlated with profile measurements of the surface determined with the microscope. (ASM)

2-45. "Surface Roughness Testing"—J. M. Trytten; *Metals and Alloys,* v. 21, January 1945, p. 138. (IAI)

3-45. "Lubrication; Newer Aspects Created by Superfinishing"—*Automobile Engineer,* v. 35, January 1945, pp. 21-23. (IAI)

4-45. "Determination of Surface Quality"—Abstract 1)—*Metals and Alloys,* v. 21, January 1945, p. 234. (IAI)

5-45. "Surfaces Inspected by Three-Dimensional Film; Faxfilm Method"—*Steel,* v. 116, February 19, 1945, p. 152. (IAI)

6-45. "Replica Method for Evaluating Finish of a Metal Surface"—Harry K. Herschman; *Mechanical Engineering,* v. 67, February 1945, pp. 119-122. Describes a new method for evaluating surface roughness which involves the use of rapidly produced plastic replicas of variable transparency. Evaluations of surface finish made by this method on five specimens which differed significantly in degrees of finish were correlated with profile values of these surfaces determined by (a) the profilometer method (as root-mean-square values), and (b) the microscope on cross-sections (peak-to-valley values). These data show that this replica method is especially sensitive for the evaluation of surfaces having high degrees of finish. (ASM)

7-45. "General Electric Method of Designating and Inspecting Surface Finish"—*Machinery,* v. 51, February 1945, p. 184. (IAI)

8-45. "The Structure of Sliding Surfaces"—G. I. Finch; *Engineering,* v. 159, March 16, 1945, p. 215. State of surface may be determined by electron microscopy and diffraction. Root cause of breakdown in oil film is texture.

9-45. "Topograph for Measuring Surface Finish"—*Engineer,* v. 179, March 16, 1945, p. 215. (IAI)

10-45. "Some Principles and Methods of Surface Measurement"—R. E. Reason; *Journal and Proceedings of the Institution of Mechanical Engineers,* v. 53, 1945, (War Emergency Issue No. 10), pp. 335-337. Same, *Engineering,* v. 159, March 16, 1945, pp. 216-217. (IAI)

11-45. "Surface Finish Symposium"—*Engineer,* v. 179, March 16-30, 1945, pp. 218-220, 230-231; *Engineering,* v. 159, March 16-April 13, 1945, pp. 215-220, 237-239, 258-260, 277-280, 299; *Automobile Engineer,* v. 35, April 1945, pp. 141-146. Discussion, *Engineer,* v. 179, March 16-23, 1945, pp. 209-211, 234-236. (IAI)

12-45. "Measurement of Surface Waviness"—C. Timms; *Engineering,* v. 159, March 16, 1945, pp. 217-220. Analysis of various surfaces and instruments. Pen charts.

13-45. "Drawing Office Specifications"—H. J. Griggs; *Engineering,* v. 169, March 23, 1945, p. 237. Standards proposed by British Standards Institution relating to symbols.

14-45. "Requirements in Surface Finish"—D. McConnell; *Engineering,* v. 159, March 23, 1945, p. 238. (IAI)

15-45. "Tomlinson Recorders"—*Engineer,* v. 179, March 23, 1945, pp. 237-238. (IAI)

16-45. "Results of Modern Practice"—F. Mourse; *Engineering,* v. 159, March 23, 1945, p. 239. Instruments replace visual inspection in aircraft work.

17-45. "Surface Finish"—*Engineering,* v. 159, March 16, 1945, pp. 211-212. General discussion of terms, machines, instruments and methods.

18-45. "Surface Finish on Production Methods"—W. E. R. Clay; *Engineering,* v. 159, March 23, 1945. Surfaces produced by grinding, honing, lapping and superfinishing. Degree of roughness and advantages of methods discussed.

19-45. "Symposium on Surface Finish: Continuity in the Production of Specified Surface Finish"—E. Swain; *Engineering,* v. 159, March 30, 1945, pp. 258-260. If a ground or honed finish is to be improved, the matter resolves itself into moderate finish with accuracy and speed of operation, as against fine finish, with slow operation coupled with the danger of generating excessive temperature, and its consequences. (ASM)

20-45. "Requirements in Surface Finish"—D. McConnell; *Journal and Proceedings of the Institution of Mechanical Engineers,* v. 153, 1945 (War Emergency Issue No. 10), pp. 341-342. Requirements of surface finish are concerned with the reduction of wear, and final decisions must largely rest on the observed results of work with known surface finishes. Paper for Symposium on Surface Finish. (ASM)

21-45. 1944 Report on Measurement of Surface Finish by Stylus Methods—R. E. Reason, M. R. Hopkins and R. I. Garrod; Published by Taylor, Taylor and Hobson, Ltd., Leicester, England, March 24, 1944, 78 pages; charts, tables, illustrations. See also review in *Automobile Engineer,* v. 35, n. 460, March 1945, p. 119. Report on work done in past few years in Taylor-Hobson Research Laboratory; basic elements of stylus instrument and limitations they may impose; various ways in which numerical assessment could be secured. Stylus instruments are built to give graph representing cross-section of surface, or numerical indication on meter, or both. (EI)

22-45. "Comparison of Surface Roughness of Highly Finished Plan Surfaces"—J. Kluge and G. Bochmann. *VDI Zeitschrift,* v. 88, April 1, 1945, pp. 179-181. *Engineers' Digest* (American Edition), v. 2, May 1945, pp. 215-216. Theory is advanced that it is less important to determine surface profile than to ascertain whether repeated refinishing of a surface will produce identical surface roughness. New apparatus developed for this. Instrument operates on the principle of throwing a parallel beam of light upon the surface under an angle of 45 degrees. Reflected beam is then passed through a lens followed by an aperture and a photocell. (ASM)

23-45. "Talysurf"—*Engineer,* v. 179, April 6, 1945, pp. 276-277. (IAI)

24-45. "Effect on Fatigue Strength"—W. Ker Wilson; *Engineering,* v. 159, April 6, 1945, pp. 277-280. Sources of surface weakness include faulty geometrical shape, fretting corrosion and wear, scaling, poor surface finish, mechanical damage and metallurgical defects. Influence of cutting, grinding and polishing on fatigue strength discussed. Strength and wear resistance can be increased by heat treatment, mechanical or surface coatings. Generally finely finished surfaces are more desired.

25-45. "Some Principles and Methods of Surface Measurement"—R. E. Reason; *Engineer,* v. 159, March 16, 1945, pp. 216-217. Standardization of measuring instruments and method discussed.

26-45. "Symposium on Surface Finish"—*Machinery* (London), v. 66, April 19, 1945, pp. 427-429. Rational specification of surface finish; requirements in surface finish. (ASM)

27-45. "Symposium on Surface Finish"—*Machinery* (London) v. 66, April 26, 1945, pp. 457-458. Continuity in the production of specified surface finish. (ASM)

28-45. "Surface Finish"—W. Ker Wilson; *Aircraft Production,* v. 7, n. 78, April 1945, pp. 189-193. Effects of various workshop operations on fatigue strength of steels are considered; surface finish of aircraft engine components are dealt with. Many useful test results are included and references made to use of shot blasting for increasing fatigue strength. Before Institution of Mechanical Engineers. (EI)

29-45. "Relation of Surface-Roughness Readings to Actual Surface Profile"—L. P. Tarasov; *Transactions of the American Society of Mechanical Engineers,* v. 67, April 1945, pp. 189-196. Studies of surface finish have shown the desirability of relating profilometer roughness readings to actual peak-to-valley distances of the type that a micrometer measures. Approximate multiplying factors for converting profilometer readings into peak-to-valley roughness have been obtained from taper sections of a variety of abrasive-finished steel surfaces with profilometer roughness in the range of 1 to 100 microinches rms. For cylindrical ground surfaces, the factor can be taken as about 4½; for other types of fixed-abrasive finishes, as 6 or 7; and for loose-abrasive lapped surfaces, as 10. These are mean values, and individual factors may deviate by as much as one-third of the main value. The factors quoted give values for "predominant peak" roughness; they should be doubled to obtain "deepest maximum" roughness, this being a second way of describing the peak-to-valley roughness. (ASM)

30-45. "Surface Finish and Its Measurement"—R. E. Reason; *Journal of the Institution of Production Engineers,* v. 23, n. 10, October 1944, Edition B, pp. 347-372. *British Non-Ferrous Metals Research Association Bulletin,* v. 25, April 1945, p. 95. Importance of physical and geometrical aspects with emphasis on the latter; basic stylus instrument; unit of measurement; graphs of surfaces; use of special instruments (auto-collimator, waviness instrument, roughness instrument with skid, Tomlinson instrument, profilometer, Talysurf) in connection with measurement of different kinds of surface imperfection. (ASM)

31-45. "The Measurement of Surface Finish"—H. P. Jost; *Liverpool Engineering Society Transactions,* v. 65, 1944, pp. 49-70; *Iron and Steel Institute Bulletin,* n. 112, April 1945, pp. 154-A-155-A. (ASM)

32-45. "Locomotive Practices"—F. C. Johansen; *Engineering,* v. 159, April 13, 1945, p. 299. Relation and importance of surface finish to life of parts.

33-45. "Brown and Sons Surface Finish Measuring Instrument; Topograph"—*Automobile Engineer,* v. 35, May 1945, pp. 203-204. (IAI)

34-45. "Surface Measurement"—*Aircraft Production,* v. 7, n. 79, 81, May 1945, p. 219; July 1945, pp. 307-308. May: Topograph, introduced by David Brown and Sons Ltd. (Huddersfield), operates on simple pneumatic principle and gives pen-record of profile of surface along selected straight track. July: For measurement of fine surfaces, Pitter Gauge and Precision Tool Co. has developed portable optical surface finish analyzer which incorporates in one unit a light source, an optical system, and a reference lens. It is claimed that this method ensures absolute accuracy of surface measurement. (EI)

35-45. "Topograph Surface-Finish Measuring Instrument"—*Engineering,* v. 159, n. 4142, June 1, 1945, pp. 427-428. Illustrated description of machine developed by David Brown and Sons Ltd. which operates on simple pneumatic principle and gives pen record 10 inches long by 5 inches wide, on paper, in 3 minutes, record being enlarged profile of surface irregularities along selected straight line. (EI)

36-45. "Surface Roughness, Waviness and Lay"—*Engineering,* v. 159, n. 4144, June 15, 1945, pp. 474-475. Editorial discussion of proposed American Standard (B46) for surface roughness, waviness and lay; revision of previous proposed standard distributed in March 1940. (EI)

37-45. "Evaluating Surface Finishes"—*Steel,* v. 116, n. 26, June 25, 1945, p. 142. Accurate and rapid method of determining type and quality of surface finish of metals utilizes clear plastic film which "flows" over surfaces. Replica then is stripped and surface examined by passing it through narrow beam of light to register irregularities on photoelectric cell. (EI)

38-45. "Surface Replicas for Electron Microscopy"—L. Thomassen and others; *Review of Scientific Instruments,* v. 16, June 1945, pp. 155-156. (IAI)

39-45. "Surface Roughness"—L. P. Tarasov; *Industrial Diamond Review,* v. 5, July 1945, p. 162. Relationship of readings to actual surface profile. (ASM)

40-45. "Optical Surface-Finish Meter"—*Engineering,* v. 160, n. 4148, July 13, 1945, p. 26. Meter for fine reflective surfaces manufactured by Pitter Gauge and Precision Tool Co. Instrument, called PVE "Critic," is made in two forms, one being for visual examination through microscope, and other arranged for both visual examination and for photographic record by means of camera attachment. (EI)

41-45. "Improved Profilometer"—*Aircraft Production,* v. 7, n. 81, July 1945, p. 339. Details of new "Q" model of Abbots profilometer for measurement of surface roughness for large variety of parts. Readings representing average roughness of surface measured in microinch units. (EI)

42-45. "Ultra-fine Surfaces on Metals"—K. Rose; *Metals and Alloys,* v. 22, July 1945, pp. 70-75. (IAI)

43-45. "Surface Comparison"—*Western Machinery and Steel World,* v. 36, July 1945, p. 311. New process reproduces faithfully specified machine finishes. It is a refinement on electroforming methods which permit plating with hard metals, and will reproduce exact facsimiles of surfaces down to the millionth of an inch. (ASM)

44-45. "Surface Measurement"—*Aircraft Production,* v. 7, July 1945, pp. 307-308. Optical meter for fine reflective surfaces. (ASM)

45-45. "Interpreting Surface Roughness Readings"—L. P. Tarasov; *Machine Design,* v. 17, August 1945, pp. 137-138. Shows how roughness measurements can be converted to linear microinches that can be visualized readily and handled in the same manner as any other linear dimension. (ASM)

46-45. "Rugosimeter; Instrument for Measuring Surface Roughness of Calendered Sheet Rubber"—M. Mooney, *Industrial and Engineering Chemistry, Analytical Edition,* v. 17, August 1945, pp. 514-517. Excerpts. *Rubber Age,* v. 57, September 1945, p. 724. (IAI)

47-45. "Optische Verfahren zur Pruefung der Oberflaechenguets"—B. Frischmuth; *Schweizer Archiv,* v. 11, n. 9, September 1945, pp. 262-269. Optical method for testing surface quality; illustrated description of various methods; details of auxiliary device with which, in combination with standard metal microscope, straightedge shadow method of O. Schmaltz can be employed. (EI)

48-45. "Surface Roughness; Proposed Standard Definitions and Symbols; Engineering File Facts"—*Metals and Alloys,* v. 22, September 1945, p. 775. (IAI)

49-45. "An Instrument for Recording Surface Waviness"—*Machinery* (London), v. 67, September 20, 1945, p. 327. Records waviness of a flat or curved surface, as instrument is moved over the face of the test piece. Contact with the surface is made by a small steel ball set in a sliding spindle. The latter is attached to a recording arm giving a continuous record. A suitable ratio of magnification is 50 to 1, and the record may be magnified again by about 50 when under optical examination. (ASM)

50-45. "Electron Microscopic Investigation of Surface Structure"—Robert D. Heidenreich; *SAE Journal,* v. 53, October 1945, pp. 588-594. Technique applicable to the study of the surfaces of rigid solids. Includes examples of structure of the bulk material as revealed by suitable etching techniques (metallography) and structure of the surface regions as they affect such factors as friction and wear, corrosion, adhesion of paints, and surface films. (ASM)

51-45. "A Bibliography on Methods for the Measurement and Specification of Surface Finish"—Department of Munitions, Munitions Supply Laboratories, Commonwealth of Australia, Maribyrong, Victoria, August 1945. One hundred articles, including outstanding papers, published between 1931 and 1945 have been abstracted.

52-45. "Measurement of Finely Finished Surfaces by Optical Interference"—C. Timms; *Journal of Scientific Instruments,* v. 22, n. 12, December 1945, pp. 245-246. Method of measuring depth and pitch of fine surface irregularities as produced by lapping or similar refined processes by use of optical interference. It is strictly limited to fine finishes where surface irregularities do not exceed approximately 0.00001 in. in total depth. (EI)

53-45. "Les Etats de Surface"—L. Robida; *Technique des Industries Mecaniques,* 1945, pp. 51-55. Surface state of metals; definition; macro and micro-geometrical deformations of surface; measurement by means of optical, electric or pneumatic methods; state of surface from physicochemical point of view; Chrysler superfinishing process. (EI)

54-45. "Rational Specification of Surface Finish"—W. A. Tuplin; *Journal and Proceedings of the Institution of Mechanical Engineers,* v. 153, 1945, (War Emergency Issue No. 10), pp. 340-341. Relation between pen record and bearing area; existing methods of specification of roughness. Paper for Symposium on Surface Finish. (ASM)

55-45. "A Short Review of Surface Finish in Relation to Friction and Lubrication"—D. Clayton; *Journal and Proceedings of the Institution of Mechanical Engineers,* v. 153, 1945 (War Emergency Issue No. 10), pp. 332-334. Surface roughness as a pertinent factor with boundary and dry lubrication and various practical cases of mixed lubrication. Paper for Symposium on Surface Finish. (ASM)

56-45. "A New Evaluation of Surface Finishes"—W. F. Klemm. *The Tool Engineer,* v. 14, n. 11, June 1945. Determination of surface finish by visual comparison with a known standard. The comparison is made with a dual microscope.

CONSIDERATION OF THE PHENOMENON OF STATIC ELECTRICITY

WITH

PARTICULAR REFERENCE TO ITS GENERATION BY THE FLOW OF LIQUIDS, AND POSSIBLE PRECAUTIONS AGAINST DISCHARGE OF STATIC CHARGES IN THE PRESENCE OF VOLATILE INFLAMMABLE OR EXPLOSIVE MIXTURES, GASSES OR LIQUIDS

CAPTAIN CARL J. LAMB, USNR

AND

C. R. ROWE, AINSMAT SOUTHWESTERN DISTRICT (PETROLEUM)

THE AUTHORS

CAPTAIN LAMB who spent three years at the Naval Academy and was commissioned in the Naval Reserve in June, 1917, has contributed seven previous articles to the JOURNAL. In addition to a long period of time in the central station and marine departments of the Westinghouse Electric Corporation, he has spent many years at sea in the Navy and Merchant Marine, and holds unlimited Marine Chief Engineer's License, steam and motor, in addition to professional Engineer licenses for the states of Connecticut and Indiana. At the present time Captain LAMB is again on active duty as Supervisory Inspector of Naval Material at Houston, Texas.

MR. ROWE has been the Assistant Inspector of Navy Material, in charge of the inspection and shipment of Navy procured petroleum products in the states of Texas, New Mexico, Oklahoma, Arkansas and Louisiana. He attended Georgia Tech and Texas University and is a Lieutenant Commander in the U. S. Naval Reserve. He formerly held positions with the Shell Oil Company at its Houston Refinery and with E. W. Saybolt & Company, commercial petroleum inspectors. He has recently been transferred to the Southern Air Procurement District, with duties corresponding to those of AinsMat in the Navy.

STATIC ELECTRICITY

Static electricity is defined by the Chemical and Engineering Dictionary published by the Chemical Publishing Company of New York, Inc., as "Electricity at rest; nonflowing electricity commonly generated by friction."

In considering the nature of static electricity, it must be distinctly understood that it does not flow in the sense that A.C. or D.C. current is considered as flowing through a conductor, but that a static electrical charge accumulates on the surface of the conductor.

In considering the general subject to static electricity, it is well to remember that there are three respects in which the behavior of static electric charge is similar to that of magnets. These are as follows:

1. Like charges repel each other.
2. Unlike charges attract each other.
3. The attraction or repulsion in both cases varies inversely as the square of the distance between them.

In addition, however, there are two respects in which the behavior of static electricity is different from that of magnets. These are:

1. Whereas magnets act only upon magnetic substances such as iron and steel, electrostatic charges influence all insulated bodies.

2. A magnet behaves as if the molecular force of magnetism prevails throughout the whole mass of the magnet, whereas an electric charge is found to exist only upon the outer surface of a conductor.

The physics text books distinguish between conductors and non-conductors of electrostatic charges according to the ease with which electric charges migrate through them. Practically all metals are good conductors. Air, mica, ebonite, quartz, wood, glass, etc., are not conductors and are classified as insulators.

The only way to charge a body negatively is to add electrons to it. Conversely, the only way to charge it positively is to remove electrons. Such a transfer is always associated with the transfer of some kind of matter, accomplished in some manner, as by motion or friction.

An uncharged conductor may become charged by electrostatic induction, if it be brought into the field of a positively charged conductor, one end of the formerly uncharged conductor having a positive charge and the other end a negative charge. Lightning, for example, illustrates and results from a case of electrostatic induction on a grand scale.

In this discussion we are primarily concerned with the generation of static electrical charges in pipe lines carrying petroleum products. It has been known for an appreciable period of time that the motion of petroleum products in pipe lines (and even tanks) can generate static electrical charges. Everyone is familiar with the chains trailing on the roadway from tank trucks, so that the tank may be conducted to and dissipate to ground static charges generated by the motion (or friction) of the hydrocarbon product in the tank.

In the fueling of planes, ships and locomotives, and in loading tankers, tank cars and tank trucks, it has been customary practice to use cable connections to ground the ship or vehicle, before making up the pipe, tube, hose or other liquid conductor. Conversely, the pipe or hose is supposed to be uncoupled before disconnecting the cable connection to ground.

Recent unexplained explosions and fires in this district caused the Administrator of Petroleum Inspection to issue the following memorandum:

"MEMORANDUM A8-6

From: AINM, Southwestern District
To: All Petroleum Inspectors

1. Recently a kerosene explosion and the fire that followed took one

life, wrecked a barge and destroyed an oil loading dock and pipelines. There have been other explosions at this and other docks, when loading supposedly safe products such as kerosene, which are equally as hard to explain.

2. After eliminating all other causes such explosions are usually attributed to static electricity. This brings up the question of whether or not adequate grounding devices were provided and used. It is to be expected that dock and vessel personnel would use less caution in grounding a vessel loading a flash product than when handling gasoline or other light products. Such an attitude is not consistent with practical safety measures as heavier oils may generate higher static charges than lighter oils.

3. For his own safety as well as that of the vessel, the cargo and the loading facilities, the inspector should observe the grounding cable and connections before approving a vessel for loading. All connections should be tight and made only to clean metal surfaces. The connection should be between the shore and vessel pipelines. The often used method of attaching the ground cable to the vessels' hull or railing with a spring clamp or clip over painted, oily or rusty surfaces should not be accepted.

/s/ C. R. Rowe"

The memorandum as issued was a step in the right direction. Further consideration of its subject matter convinced us that we did not have much actual knowledge of the generation of static electricity, or the proper steps to prevent explosion or fire due to it, when handling petroleum products.

A search of the available instructions and literature brought to light an old copy of a page from a book used to train carrier personnel, which is quoted below:

"TRANSFER OF GASOLINE

When gasoline is being transferred, as in receiving gasoline aboard, fueling aircraft, or pouring into a safety can, care must be exercised to prevent sparks, which can occur through discharge of static electricity induced by the flow of gasoline in the hose. Due to differences in electrical potential, a spark will probably occur when the two ships, the aircraft and fueling hose, or the can and the other container, are connected by a bonding wire. This bonding connection is made before any flanges or caps are removed, thus eliminating the possibility of the presence of gasoline vapors. Once the bonding wire is connected the static electricity induced by the flow of gasoline is continuously grounded without a spark.

In fueling aircraft, the hose nozzle will be grounded to the aircraft by establishing a firm metal contact, using a flexible copper wire on the nozzle. After grounding is completed the cap will be removed, the nozzle will be inserted into the filling hole, and the flow of gasoline will be started. The grounding connection will be left in place until fueling is completed and the cap has been replaced.

When gasoline is received in bulk, as on airplane carriers, tenders and oilers, it is taken on board by hose from the source of delivery. Before connecting the hose, an insulated copper cable, at least No. 4, U. S. gage, shall be connected between the source of supply and the receiving inlet, with sufficient slack in the wire to prevent tension. The wire shall remain in place until the hose is removed, and a single-pole electric ground safety switch shall be provided for easy operation at some dis-

tance from either end of the hose, insuring that no spark will occur except in the switch, which should not, be opened when the hose is in place. Electrical bonding wires are fabricated into the hose wall to ground the hose terminals. The No. 4 gage ground wire is also connected to these hose terminals as an added caution to guard against the accidental failure of the hose and hose wire. This would occur if the supply and receiving ships drifted apart to the extent that the hose would break and spill gasoline. Immediately after the gasoline started to issue through the hose failure, the hose wire would also break and thus give a spark to ignite the gasoline. This spark is avoided by use of the alternate ground wire, which is long enough to remain intact well beyond the point at which the hose would fail. Some ships are equipped with quick-release hose couplings, to avoid hose breakage under these circumstances, but the alternate ground wire is still essential.

If gasoline is to be filtered, wire-screen filters should be used when possible. Occasionally it is filtered through chamois, to detect small particles of dust or water. In this case the chamois or other filtering material is used in a thoroughly grounded metal funnel so fitted with wire gauze that the filtering material can be laid on the wire gauze and kept in intimate contact therewith. The hose nozzle is thoroughly grounded."

It seemed to us that the above instructions were superior to the ones issued in Memorandum A8-6, but certain questions arose which seemed to require an answer. Why Number 4 cable? Why must it be of copper? The use of the switch seems necessary, but in our judgment it should be an explosion-proof one.

We are considering, actually, static generators. The larger the area of the tube, pipe, hose or container, the greater should be the electric charge it would hold. As the pipe or hose is increased in diameter, it would seem that a greater charge could be generated. Increased velocity or pressure will result in greater friction, and as a result, in the more rapid generation of static electricity.

It is probable that both temperature and humidity influence the efficiency of the particular type of static generators we are considering. It may also be possible that such pipe lines or hose lines may receive induced charges from external forces.

Since it is known that the flow of petroleum liquids thru pipe and hose lines generates static electricity, the efficiency of such generation, or in other words, the rate and potential of the static electricity generated, would seem to depend on the following factors:

1. Length.
2. Diameter.
3. Velocity.
4. Pressure.
5. Temperature.
6. Humidity.
7. Whether stationary, or in motion as the hose lines, when fueling underway at sea.
8. Whether susceptible to electrostatic induction.
9. Dielectric of the liquid being pumped.
10. Possibly, the material of construction of the pipe or hose.

The safety engineer of one large oil refinery has reported to us distinct evidence (electrostatic discharges) of static generation in the flow of dry steam thru cleaning jets.

Underground gas transmission lines have excellent protection against electrochemical corrosion, generally this consists of magnesium anodes, well grounded several feet from the line, and connected to the line by cable. The anodes are so proportioned along the length of

the line that they afford protection against electro-chemical corrosion and also bond the line to the ground as protection against electrostatic discharges.

To us it seems apparent that engineers have recognized the fact that pipe and hose lines carrying petroleum products are static generators. Further, some protection has been provided, of various types and to various degrees. We believe, however, that there is at present litle exact knowledge about the subject, and that more definite data can and should be ascertained. A proper research program into the subject could produce scientific knowledge as to the extent of the problem, and its best solution. As a result, each pipe or hose line could be protected by well engineered safety connection against static discharges, of the right material and capacity, fitted with an explosion-proof switch and well grounded.

It has been the purpose of this paper to arouse interest and discussion. Frankly, we should like to learn much more about this subject. It is possible that much more is definitely known, and on record. If not, we believe it would be of real value if the proper Government agency could conduct research and experimental work to find the answers.

APPLICATION OF RESEARCH TO THE GAS TURBINE

ACKNOWLEDGMENT

This article is extracted from a paper read before a meeting of the N.E. Coast Institution of Engineers and Shipbuilders on December 12, 1952. Written by MR. HAYNE CONSTANT, it was published in the January 1953 issue of "The British Motor Ship."

I am choosing for the period of my review roughly the past six years covering the time that elapsed since the formation of the National Gas Turbine Establishment in 1946.

A research organization that wished to play safe could take up an impartial attitude—could sit on the fence—and pursue several possible lines of attack. In fact, people often go so far as to take great credit to themselves for their impartiality, attributing it to the true scientific spirit. Such an attitude might have virtues in a timeless world in which progress halted until the issue was decided. But in the real world engineers usually have to make their decisions with inadequate knowledge and cannot afford to wait until the issues have been clarified with scientific detachment.

The second pillar of my philosophy of research is therefore simply this, that it is necessary in most engineering research to make up one's mind at an early stage in the proceedings, which of a number of alternative courses one is going to follow. This must be done, if necessary by divine inspiration, and certainly by the exercise of judgment, common sense and intuition, before all the necessary facts are available. One should then apply the first principle and concentrate all the available resources into a single concentrated effort and pursue it until success is achieved or one becomes convinced that a mistake has been made.

There is another pitfall for those who are working on applied research, on work, that is, which is not producing knowledge that will be of permanent value, but is rather finding solutions to problems that are of only transient interest. Such workers face the danger that the problem which they are trying to solve may disappear before the solution is found, and all their work may go for nought.

This disappearance of a problem is usually due to the direction of technical progress changing, so that new targets are raised and the old ones become of no further interest. The development of a turbine with a cooled rim to its disc, would, for example, result in the disappearance of the problem of developing

bearings capable of operating at higher temperatures. The only way of reducing the amount of effort that is wasted in this way is by a judicious selection of the problems on which one is going to work. Considerable judgment is required to foresee the possible changes in the direction of technical development, to assess which are the real immovable difficulties that have to be surmounted, which are the obstructions past which a way round can be found and which are the mirages which only exist when one is feeling depressed.

ECONOMY OF EFFORT

Finally, there is the problem of economy of effort. I have had considerable opportunities for seeing the effort in manpower and money that is expended, both within and outside Government organizations, on basic and applied mechanical research, and I have been shocked by the tremendous expenditures that have been required to obtain sometimes trivial information.

Most researches are failures to the extent that they do not succeed in solving the problem that was their objective, or in giving the information that it was hoped they would give. The only reason why research pays off is that when a piece of work is successful the advantages that accrue more than make up for the losses on all the failures. It is therefore of the first importance that we should try to increase the percentage of success. In my opinion, this means very careful selection of the problems on which one is going to work. It means picking those problems which are suitable in their nature and their difficulty for the kind of men and facilities that are available. This is a novel approach which, I think, is not generally accepted.

I had formed an adverse opinion of the possibilities of using ceramic materials for blades about 15 years ago. I obtained sufficient support in the Establishment to reach a decision that we would attempt to attain high temperatures by the use of cooling rather than by the use of uncooled materials, such as ceramics.

We decided against working on closed cycles on the grounds that once the cooled turbine was developed, the maximum temperature of the open cycle would rise above that of the closed cycle and give a higher efficiency. We objected, moreover, to the greater complexity and complication of the closed cycle for a power plant, the main point of which, after all, was its simplicity.

Having completed the rather negative process of deciding what not to do, we had to take one further step before we could crystallize our program of work. This step—and it is one which we repeatedly take—is the process of trying to visualize the layout and thermodynamic cycles that are likely to be used for different applications, to assist us in anticipating the problems that the gas turbine is likely to throw up. It has become necessary for us, therefore, to spend a certain amount of time making comparisons of the various possible forms of engine for different applications. This is a most interesting occupation, but also a most dangerous one. Quite a small error in the assumptions made can be magnified in the ensuing argument and lead finally to totally wrong conclusions. An even more potent source of error can be due to the effect of faulty judgment in deciding what to take into account and what to neglect.

The examination that we made of the application of the gas turbine to railway traction led us to the conclusion that what was required was a simple form of engine running on liquid fuel and driving from a separate power turbine through a mechanical, rather than an electrical, transmission. Tests that

we made to determine the torque characteristics of multi-stage turbines showed that no change-speed gearbox would be required. We thought it likely that such locomotives would prove more suitable abroad than on the railways of this country, where high traffic densities are forcing us towards electrification. It is too early to say whether these views were correct.

We foresaw the use of gas turbines for stand-by and peak-load uses in works power stations, using simple cycles with efficiencies of up to 25 percent. We thought it unlikely that there would be much scope for large base-load power stations unless some simple means of coal burning could be devised.

We have always been very optimistic about the likelihood of the widespread application of the gas turbine to marine propulsion, but rather vague about the form which the engine should take. This, I think, springs from a consciousness of the extent of our ignorance of marine affairs. When, for example, we note that marine architects often design their engine-rooms much larger than is necessary because of a rule laid down before any of them were born, we realize that our mental planes do no intersect.

THE PROBLEM OF THE MARINE GAS TURBINE

The concept that we first arrived at for the large marine engine was that of obtaining the maximum possible efficiency and flexibility by dispersion. We envisaged a power plant of the double-compound type with heat exchangers and intercoolers, the various components of which were connected together by trunking. Examples of such power plants have since been produced by various manufacturers. Today we are not so sure. We believe that weight and bulk should mean more to the marine engineer than, in fact, they do. We have a growing feeling that the integral power plant, consisting of a single piece of machinery like a Diesel engine, may, in fact, be the right solution. Such an engine might be a little less efficient than its dispersed competitor, but it would be vastly lighter, cheaper, and more compact.

There are so many possible arrangements and cycles that can be used in the gas turbine that a great amount of exploratory work, extending over several years, was needed before we could be sure that we had found the best answer for each duty. In the course of this work we explored over a hundred cycles and variations of them and had to work for as much as six weeks on some of them in order to determine the engine performance under part-load conditions.

Once the single-stage performance is known, the overall multi-stage performance is predicted by the addition of the appropriate number of stages. We used to do this by simple addition, in the belief that one stage would act independently of the presence of the adjacent stages. We know that the tests on which this belief was based were misleading, and that we have to apply a correction, known as a variable work-dome factor, to take account of the fact that there is a progressive change through the compressor of the variation of axial velocity with radius; or, in other words, a thickening of the boundary layer takes place.

In some respects we have during the past five years made great progress in a circle, returning approximately to our starting point. For example, all our early work on compressor blading was done on blades with a circular-arc backbone. Simple theory, confirmed by mis-

leading wind-tunnel tests, then made it clear to us that a change to a parabolic-arc camber line would give better performance at high Mach Numbers. We therefore started new programs of cascade testing to give us the necessary basic data on parabolic-arc blades.

In spite of these rather frank remarks, it must not be concluded that no progress has been made. In spite of the false starts, the changes in direction, the failures of judgment and of understanding, which are inevitable in work designed to extend the frontiers of knowledge, great progress has nevertheless been made. The over-all result of the increase in knowledge which has been attained is that the polytropic compressor efficiency has risen from about 88 percent to about 91 percent and the maximum pressure ratio attainable from an axial compressor, which was about 4½:1 in 1945, is now over 7:1—greater than required for most gas-turbine applications. We now have the essential data on which the aerodynamic design of compressors and turbines is based.

The other essential component of the gas turbine, the combustion chamber, also has its problems. Combustion is a particularly difficult subject to study in that it involves aerodynamic, chemical and physical problems. Its study is not, of course, an occupation reserved for the gas-turbine engineer. It has been a preoccupation of many organizations and interests long before the first gas turbine ever ran. The only excuse for the turbine engineer's entering this field is that he has introduced all the old problems in a more acute form and, at the same time, offered a new philosophy or outlook to assist in dealing with them. He could, of course, have taken a Primus stove or the blowlamp as they stand, but he preferred to say "We must reduce our combustion chamber to one-hundredth of that at present possible and here is a new technique to enable us to do it." Or he could have burnt heavy oil in the same way as it has been done under marine boilers for several decades. But the gas-turbine engineer wanted less space and a higher temperature, and so again decided to make a fresh start.

I only mention a few of the many researches on basic combustion phenomena that have been undertaken. We have developed an experimental technique for measuring the spontaneous ignition temperatures of fuels. From this work we have established the ignition delays for a variety of fuels under turbine-operating conditions and measured their variation with pressure. A fairly complete picture of the mechanism of evaporation of a liquid fuel droplet has been built up. It has, for example, been found that at high temperatures the effect of fuel volatility is negligible, while at low temperatures its effect dominates the whole process.

Again, it has been shown that the drag of a droplet increases upon burning at a low Reynolds Number and decreases when the Reynolds Number during combustion is high. The formation of cenospheres and coke-like particles as the result of the combustion of heavy fuel has been demonstrated and explained. The effects of air vitiation upon the processes of combustion have been determined and their influence on the design of a chamber with exhaust-gas recirculation has been demonstrated.

An important problem, and one which is in every respect suitable for being worked on at the Establishment, is the cooled turbine. Although considerable thought had for some years been given to the problem of turbine cooling, it was not until late 1945 that we were in a position to make serious start. At that date we were aware of the work done in Germany during the war. We were not attracted by it partly for obvious psychological reasons and partly on technical grounds which I believe to be valid.

We started the work with a clear preference for the use of water cooling. This was influenced by some preliminary experiments we made with water-cooled Perkins tubes in a rotating rig. Within a year our attitude had changed to one in which we believed that liquid cooling—using a substance other than water—was the most desirable method, but that air cooling was very much easier. When the moment came for a decision to be made, we decided that the first blades to be tested should be air cooled with the air passing radially through the blades, and that these should be followed up by blades internally cooled by water in Perkins tubes.

During the past five years much ground has been covered and much information has been gained. We have tested various forms of blade in wind tunnels up to 1200 degrees C. in order to determine the heat-transfer coefficients both gas-to-metal and metal-to-air. We have carried further our experiments with Perkins tubes, we have tested a turbine with blades internally cooled with water, another with blades externally cooled by water sprays, and yet another with blades internally cooled by air. We have developed combustion chambers operating at temperatures up to 1200 degrees C.; we have experimented with ducting and chambers having cooled liners made from porous and other materials. After all this experience, our original view, that liquid cooling is better than air but more difficult, still holds good.

The work has been remarkable for the consistency with which our views have been held, the principle inconsistency being the way in which our judgment as to the most important problem has shifted, back and forth between the problem of manufacture of a cooled blade, on the one hand, and the problem of cooling large areas of stationary ducting without excessive heat loss, on the other. Our current view is that the problem of cooling ducting has now been solved, but we have yet to see a design for an inexpensive but efficient cooled blade.

The most ravenous consumer of bulk and weight is the heat exchanger. Until recently we had to accept it as the only method of giving good fuel consumption. Now, however, the cooled high-pressure engine is on the point of emerging as a competitor, and one which we believe is likely in the long run to win the day. We have therefore brought our work on heat exchangers to an end.

ACCENT ON ACCESS THE "INS" AND "OUTS" OF MACHINERY SPACES

JOHN R. WRIGHT

THE AUTHOR

A native of Washington, D. C., graduated from the U. S. Naval Academy in 1940. He served in the Navy in engineering billets and at the Post Graduate School at Annapolis until 1948. Since then he has been employed in the Machinery Design Division of the Bureau of Ships in a civilian capacity.

INTRODUCTION

Machinery arrangement design is a complex art which has in most respects kept pace with the technological improvements reflected in the modern warship. There are, however, certain details of machinery arrangement practice for which no sound design principles appear to exist. A typical example would be the provisions of machinery space access. While this may well be regarded as a detail, it is nonetheless a vitally important feature of warship design. Perhaps no other single element of combatant vessel design directly involves such conflicting considerations of personnel safety and water-tight integrity as the provisions for machinery space access. It therefore seems reasonable to presume that some useful purpose might be served by attempting to analyze specific requirements, and establish acceptable design criteria with respect to machinery space access in general.

The water-tight integrity of machinery spaces has always been regarded as a matter of vital importance in warship construction. Thus, the piercing of transverse bulkheads by doors is tabu, and machinery space access is strictly an "up and over" proposition. Unfortunately, it is at this fundamental level that all semblance of access standardization disappears; as is evidenced by the great variety of access arrangements provided in existing combatant vessels. Design is admittedly a process that thrives on compromise, and thus minor differences are to be expected. However, the basic principles of water-tight integrity apply equally to all major combatant vessels, regardless of type. A suspicion therefore arises that so far as the machinery arrangement designer is concerned the degree of importance accorded water-tight integrity decreases in proportion as the design project increases in complexity. Accordingly, as a design progresses, a serious compromise of fundamental space-integrity may be incurred (perhaps unintentionally) in favor of, say, providing a more conveniently located pump.

If we wish to prevent such dangerous expedients as may well jeopardize an entire main machinery space in battle, and at the same time, avoid the recur-

ring problem of access now common at some stage in all design developments, then we need only to establish acceptable standards of access and adhere to them to the fullest practicable extent; specifically justifying any and all deviations. These standards should include considerations of type, size, number, and location of major machinery space accesses.

GENERAL

A complete absence of access openings is the ideal solution to threats against water-tight integrity. While this is an unrealistic solution it does suggest two very practical rules, namely —minimize the number of access openings, and minimize the interval they are open. The problem then arising concerns a determination of the various necessities for access. During the recent war access openings and associated trunks were used for personnel traffic, material traffic (machinery components, repair equipment, damage control equipment, etc.), gravity drainage routes for de-watering upper spaces (flooded from sea or by fire hoses) via the more readily pumped machinery space bilges, suction wells for portable submersible pumps (used to de-water flooded machinery spaces), and as an alternate ventilation supply route when use of normal air inlets also introduced smoke.

While the foregoing is indicative of the vast range of uses to which access routes are adapted, it also serves to emphasize that personnel traffic is not only more or less involved in all other uses, but represents the only continuous (as opposed to highly occasional) use. Except for personnel traffic all uses of access are largely incidental to the existence of the access (and could otherwise be provided for, as by semi-fixed bolted plates) and do not therefore constitute the reason the access is provided. It is clear then that the primary need for access is personnel traffic.

Unfortunately little information as to the manner in which access provisions served this primary purpose during the last war is available. In this respect a means of access is like a parachute—when it works it merits no comment; when it fails no one survives to comment. However, in the following analysis the controlling consideration will be the suitability of access provisions with respect to their primary use—personnel traffic.

TYPE

Experience gained in the recent war emphasized the desirability of the following features with respect to access openings:

1. No openings into trunks are justified from other than the machinery space served and the upper exit compartment.
2. Access routes should be trunked from the machinery space overhead to above the waterline.
3. Upper exits should be coamed out even though above the waterline.

All access openings and routes should be primarily designed for personnel traffic and for that reason should provide for quick-acting closures, since such traffic is not only fairly continuous but frequently hurried. It is obvious that slow-operating access openings only encourage their being left open or partially secured; and neither condition can be tolerated in the face of the increased threat of surprise attack. Moreover, if complete absence of openings be recognized as the ideal, then minimum open interval most nearly approaches that ideal. And lastly, the machinery spaces are below the waterline, and flooding from the sea represents the fastest-

traveling damage potential short of actual explosion. The full import of these considerations is simply that where large hatches are involved they should in all cases be fitted with quick-acting scuttles.

One access route per space should incorporate the maximum number of features adapting the access to other secondary uses, in so far as such features don't compromise the requirements for personnel traffic. Since such uses are highly occasional they may incorporate slow-operating features, even including removable bolted plates.

Broadly speaking there are only two fundamental types of access—normal and emergency.

Normal access is designed for continuous use, and the most rapid and convenient use compatible with the all important objective of maximum watertight integrity. It therefore involves inclined ladders and is unenclosed within the space it serves; but is trunked outside the machinery space to above the waterline so as not flood to or from intermediate deck level compartments.

Emergency access is conceived primarily as an alternate escape and otherwise infrequently used access. Perhaps the prime necessity for alternate escape routes consists in the possibility of an overhead barrier of steam, gas, or smoke; and accordingly this type of access should be trunked to the lower machinery level. Doors in all trunks should open inward, as there have been instances where doors opening outward could not be opened in emergencies due to obstructing debris or the rising head of flood water within a space.

To minimize weight and space penalties all trunks should be vertical. A vertical trunk offers many advantages with respect to secondary uses of access, while a slanted trunk does not conversely benefit personnel traffic. For example, a straight-drop trunk provides an excellent means for raising and lowering cumbersome equipment by improvised hoists. It is similarly best adapted to portable ventilation and air line rigs (as used in navy yards or in battle emergencies), requiring less material, and being easier to so rig. During the recent war emergency trunks proved to be ideally suited for lowering submersible units to pump out flooded spaces, and also served as convenient means of draining upper level spaces into machinery space bilges.

The foregoing implies vertically lined up hatches within trunks, and ladders one over another, which incidentally requires less space than any other arrangement.

SIZE

War experience emphasized the obvious fact that if scuttles are warranted at all, they should be sized to facilitate personnel traffic wearing wartime equipment such as life belts, etc.; and also that they pass submersible pumps, portable blowers, etc. In this respect the 18″ scuttle appears to represent an unrealistic ideal. The 25″ scuttle should be standard for escape trunks (except when their installation would involve cutting stringers or piercing strength or ballistic decks, where a 21″ scuttle should prove to be a satisfactory solution), since these scuttles represent the *only* opening therein, and are fitted directly in decks. On the other hand it appears desirable to standardize on the 21″ scuttle as *secondary* openings in normal access, hatches; this size representing a compromise between the conflicting demands of ease of passage and the necessity of increasing hatch strengthening to compensate for increased scuttle size.

All hatches, incorporating 21″ scuttles must have no dimension less than 36″. Also, to provide a minimum head clear-

ance of 7′ on a 69° incline a 42″ hatch opening appears desirable. We thus conclude that a 36 x 42 hatch is the optimum size, reconciling adequacy and minimum openings. All normal access routes designed strictly for personnel traffic should be sized accordingly. However, one access route should provide for removing short life components of major machinery items, occasional machinery repair equipment, etc. These provisions should be made in a normal as opposed to emergency route because every other consideration permits of the emergency route being smaller than the normal route, and the emergency trunk must in fact be enlarged to 3′ x 3′ merely to take a 25″ scuttle. However, this use is so occasional, and so inferior to the every day wartime desirability of minimum openings, that it is believed a semi-fixed access (such as a bolted plate incorporating the standard hatch) is sufficient. A larger hatch to permit personnel traffic and, say, navy yard ventilation rigs at the same time is unnecessary, as the emergency trunks can be better utilized for the latter rigs; having no inclined ladder interference. Also, time is not of the essence, since ladders and possible between-ladder-platforms would have to be removed prior to use anyway.

Normal trunks would be 3.5′ x 4′ or 4′ x 5′ depending on whether more than one level of ladder was required, and hence a return platform for reversing direction between ladder levels. The bolted plates could therefore be sized according to trunk size, but in no case should they be less than 42 x 48.

NUMBER

It is axiomatic that the number of openings should be a minimum, particularly in strength and ballistic decks. This contention was substantiated in the recent war. Moreover, the increasing probability of surprise attack via rocket missiles and craft, and the more potent air-borne dangers incident to developments in radio-active weapons and bacteriological warfare portend even increased emphasis on minimizing openings in future designs. This is true notwithstanding the provisions for an emergency control station, since radiation effects persist; and refuge in the emergency station is to no avail if a surprise attack finds the vessel so opened as to be a prime target for extended internal flooding.

Granting that access is required, the ideal objective is one opening. This follows from the fact that most machinery spaces are below the waterline, and the threat of flooding is a primary reason for minimizing openings. The presence of high pressure steam piping is adequate justification for an alternate access in a major machinery space, since high pressure steam represents the only internally stored potential energy danger. Why this alternate route should extend to the lower level has already been discussed above under "Types." The size of a space may also justify an alternate opening, where it may be reasonably imagined that conventional damage could demolish or obstruct one and not the other. Generally, size may be considered sufficient to warrant an alternate access only when a space extends the full width of the vessel. Neither "steam" nor size can normally justify more than two access routes. The only factor that might warrant more than two routes would be a consideration of personnel traffic, or more specifically, the number of persons assigned to the space during battle. In this respect possibly an arbitrary time-rate of evacuation would be suitable criterion upon which to base the number of openings. It seems reasonable to predicate evacuation on an instantaneously developed atmospheric condition rendering the space untenable,

because such conditions cripple *personnel* only, and more atmospheric disturbances of this character are envisioned in future conflicts as aforesaid. Conversely, flooding would be a poor index for establishing an evacuation time-rate as flooding time varies too widely, affects material as well as personnel, and most important—is the best argument in the world for less openings. All things considered, four openings are regarded as the practicable maximum. In the case of three openings the odd access should be of the type extending to the most populated machinery space level. The controlling factor in determining the number of access routes should be that which indicates the greatest number as being required—steam piping, space size, number of persons.

LOCATION

The lower end of the access should be so located as to open into clear or work areas, giving direct and unobstructed routes for personnel, and straight unobstructed bilge "drain and pump" drop. Upper ends should be so located that no two openings from the same lower deck space open into the same upper level water-tight compartment. Trunks should be vertical, and hatches and ladders should line-up vertically.

Long dimensions should be fore and aft, and scuttles so positioned as to facilitate traffic rather than symetrically disposed.

When a space has only one access it should be (subject to previous conditions) as close to ship's centerline as possible. Where two access routes are provided they should be located diametrically opposite within the space, with the emergency access route as close to the centerline as possible. Where three access routes are used the two of like character should be port and starboard, and the odd one placed as close to the centerline as possible. Where four access routes are provided two should be emergency access routes and they should preferably be fore and aft on the centerline with normal access to port and starboard. Centerline locations for emergency routes are generally desirable because lower level work areas generally are in or extend to the center, and such locations are more remote to damage from either side, and more remote from flooded pockets due to list of the ship.

CONCLUSION

It is to be hoped that the criteria presented above will be of some interest to operating engineers, as well as prove of benefit to machinery arrangement engineers. The latter should not, however, regard the proposed principles as established and inffexible facts. Machinery arrangement design is an advanced art involving compromises in a multitude of often conflicting intangibles. Such an art can never be reduced to an exact science. However, it would appear that the considerations applied in the foregoing analysis should in any case enable arrangement engineers to more realistically evaluate the cost and effects of compromising certain access requirements. At the same time, a knowledge of these considerations may serve to explain to operating engineers what heretofore might have appeared to them as a lack of accent on access.

THE FUTURE OF AUTOMATIC MACHINERY

ACKNOWLEDGMENT

MR. NORBERT WIENER, of the Department of Mathematics, Massachusetts Institute of Technology, is the author of this article, which was presented at the Annual Meeting of the American Society of Mechanical Engineers in December 1952. The article was published in the February 1953 issue of "Mechanical Engineering."

The gradual encroachment of automatic machinery on the function of mankind and its social significance is no novelty. For a considerable period toward the end of the past century Samuel Butler had been preaching that the machines were endowed with a sort of pseudo-life of their own, and that they were destined to develop the pseudo-life into a rather complete life, and to struggle with mankind for the control of human destiny. This was in a large measure intended as a figure of speech, even though it was expressed by a very imaginative and intuitive man, whose figures of speech possessed such vitality that they were often conjectural statements about the future rather than mere metaphors.

The remarkable thing is that at the time at which Butler was writing, and even at the much earlier time at which he was forming his ideas, machines were much less than they have since become, and were primarily devices for replacing human power and energy—mere extensions of his arms—rather than what they have since become; devices with a modicum of discriminatory judgment of their own. It is true that the seeds of modern servomechanism were already in Watt's ball governor for the steam engine, and that James Clerk Maxwell had given an adequate and very modern theory of this in 1868. It is also true that the beginnings of the technique of computing machines had existed for two centuries, and that Babbage had started an elaborate and flexible program of mechanical computation. Yet, neither the servomechanism nor the computing machine could be more than a sporadically useful device until the ripening of the modern techniques of electrical control and amplification, both dependent on the existence of such devices as the vacuum tube, with its simplicity of structure, its cheapness, and its extreme economy of power.

For it was just because of a lack of devices of those properties which the vacuum tube possesses, that the ambitious and mathematically well-thought-out attempt of Babbage came to grief. Babbage, for all his intelligence was not a mechanical genius. His apparatus consisted in long trains of gears meshing with gears; and the frictional forces were multiplied to such an extent that the device soon became too stiff to move.

It is true that these difficulties can be overcome up to a certain point; and Pascal was already aware of this in the seventeenth century. It does not appear that Babbage was aware either of the extent of these difficulties or of the means by which they could be overcome.

The first really good tryout of long chains of control mechanisms dependent sequentially upon one another has taken place in the construction of high-speed digital computing machines. While the earliest models of these were primarily on a mechanical basis, they have been so far superseded in speed by electronic machines of comparable reliability that the mechanical devices, except for very special purposes, are on the verge of obsolescence. We thus possess a well-developed technique of devices which make yes-or-no decisions on the basis of previous decisions according to a scheme given in advance, and we must consider other devices of this sort as well within the range of possibility.

All this was not to be thought of at the time of Butler. It is only by a profound act on intuition that he was able to dream of what we may call the second industrial revolution; the revolution which replaces, not merely the human being as a source of energy, but the human mind as a source of low-level decisions, by manufactured instruments. I have commented repeatedly on the fact that the human brain also has an aspect, in which it seems to operate by decisions of a yes-or-no character, which are also based on previous decisions.

In calling the public attention to this very vital parallelism between the brain and the computing machine, I have opened a veritable Pandora's box. My statement has been interpreted as meaning, not only (as I have claimed) that we are within measurable distance of the automatic factory, in which the functions of the routine worker are taken over by electronic devices, but that we are in sight of a new era, in which the translation from speech to writing, the translation from writing to speech, the translation from one language to another, and the functions of the file clerk and librarian, and of other custodians of information, which is to be made readily available to all, shall take place without human intervention.

In this expectation, I think that our gadget-conscious public has shown an unawareness of the special advantages and special disadvantages of electronic machinery, as compared with the human brain. The number of switching devices in the human brain vastly exceeds the number in any computing machine yet developed, or even thought of, for design in the near future. The volume of the smallest tube is millions, or even billions the volume of a neuron; and the neuron probably represents far more than a single switching device. Even when the transister is so perfected that we can make a satisfactory computing machine out of transisters instead of vacuum tubes, we shall still be far from the compact and manifold complexity of the brain. On the other hand, the vacuum tube already has far outstripped the corresponding nervous mechanism in speed, and probably in reliability of action. This power of the vacuum tube to work on a time scale much smaller than that of the brain, gives back to the computing machine a measure of the efficiency lost by its coarser spatial grain.

There are certain parts of a computing machine in which we do not yet see how we can buy the equivalent of its spatial inferiority by paying for this with its advantages in speed. Computing machines and brains alike store information; but the storage of information in the best computing machine yet thought of does not compare with that of the brain. Thus the brain is at its best in the performance of operations involving a great deal of stored information and a very complex synthesis of this information. The computing ma-

chine or factory-control machine, on the other hand, is at its best in the speedy and accurate performance of relatively simple operations.

It might be thought that the complexity of the process of memory and cross reference involved in the most precise and rigid thinking in action would be greater than that involved in our everyday speech. I do not believe this to be the case. The success of the computing machine in the treatment of arithmetic is in supreme contrast to our failure to reduce moral and aesthetic judgments to any simple method of coding. Such a book as "The Aesthetic Measure" by the late G. D. Birkhoff shows the feeble success of one of the greatest analytical minds in accomplishing the rudiments of this task. To be an art critic requires a vast array of cultural experience, historical knowledge, and emotional scope and integrity. The number of yes-and-no decisions before it is possible even to begin such a task is so enormously greater than the number of yes-and-no decisions for the postulates of a very complicated mathematical system, that all comparison is utterly ridiculous.

Thus the precise and accurate can be cleared up with one or two statements, whereas the vague and emotional needs the whole experience of a lifetime to evaluate with any authority. Such a simple statement as "John is a good man" cannot be made by anyone who has not wide experience of people. What we ordinarily take to be the translation of this into another language will very seldom answer to the same experience in all respects. We shall ordinarily say that "a good man" and "ein guter Mensch" mean the same thing; and they do in so far as any equivalent is possible between words based, respectively, on the mores of England and America on the one hand, and of Germany and Austria on the other. Yet these mores, similar as they are, are not identical; and a storage of the whole code lies behind the corresponding word.

Here I have taken two words which translate into each other as precisely as two words can. In the average case the translatability of words from one language into another is much less. Who has not sought for an English equivalent of "gemütlichkeit" or for a German equivalent of "fair play"? The very fact that English borrows a word for justice from the milieu of the athletic field is significant; and while it may be understood generally in the athleticized world of the fifties, it could not have had its full meaning on the continent of Europe in the middle of the nineteenth century.

I cannot see, then, that the machine for the translation of one language into another is imminent. I cannot even see that we are near a machine, which will take in spoken language and give out a typewritten text, or vice versa. These machines would be extremely useful, one for the deaf and one for the blind. Those who are very sanguine about the immediate future of these machines do not realize that written and spoken English are never exact equivalents of one another. Quite apart from the idiosyncracies of English orthography and pronunciation, there is no very precise code by which the separation of words in printing, the use of punctuation and capitals, and the other devices at the disposal of the writer or typist, can be made equivalent to the timing and intonation of speech. In general the correspondence between speech and writing must go through an understanding of the meaning of the written or spoken language.

Translation machines of any of the sorts mentioned (except in a very rudimentary form) are thus rather remote. They involve the transference to machinery of human values, human characteristics of learning, and the like, and thus involve the attempt to replace the brain by the machine just where the

brain is at its best and the machine is at its worst. I do not doubt that the machines can be made to learn, and even to evaluate, but to make them learn and to evaluate after a specifically human pattern involves much more precise knowledge of the human system of evaluation and the human methods of learning than, I imagine, is now in the hands of the constructors of cybernetics machines—or indeed, of anyone else.

These same difficulties will militate against the perfection of the art of cataloguing and cross-reference-making by machine, which has been much touted for some years in some influential quarters. It is not difficult to search for the affinities of an article, when one classification has been given, *and the affinities of this classification are already recognized.* However, the first true recognition of the affinities of different subjects often requires an intellectual effort of high order. For example, it is not difficult to be aware that mathematical epidemiology and the kinetic theory of gases have much in common, once the similarity has been pointed out, but it is too much to ask of any extant machine, or any to be expected in the near future, to recognize this similarity before it has been pointed out. In searching the literature for such similarities, it is much better to recognize that an author is likely to use the same kit of tools in different subjects, and to link up all the writings of the authors who have written on one of these subjects, with a critical eye to the idea structure of their writings, than to depend on an existing subject index, no matter how elaborate. A mechanical cataloguer will long remain as inferior to the expert human cataloguer with scientific knowledge, as a peg-leg is to the flesh-and-bone article.

I bring up these shortcomings of the linguistic and intellectual use of manufactured apparatus, just because I wish to define and mark off these fields in which mechanical apparatus is already the competitor of the human worker, or threatens to become the competitor in the near future. The steam engine soon became the competitor of the galley slave, just because the galley slave was being used in a most uneconomical manner, as a source of power and scarcely anything else. There still exist factory tasks in which human beings are used for discrimination instead of for power, but in which this discrimination is on such a low level that it represents an employment of human faculties almost as imperfect and uneconomical as that of the galley slave.

It does not require the full complexity of the human organism to paste labels on tin cans, nor to sort and pack spears of asparagus. It does not require the full complexity of the human organism to read the instruments in a chemical factory, and to turn switches or valves in accordance with a code determined by their readings. It does not even require a very high and human type of labor to turn a wrench and tighten one or two bolts per car in an assembly line. In all these cases, the over-design of the human mechanism used is as gross as if we were to adjust the degree of opening and closing of a barn door by an interferometer.

In a factory in which the greater part of the employees perform routine tasks, and management pays attention solely to technical operations, there is a great analogy with the team of semiskilled computers presided over by a mathematician. The mathematician sets up the problem, determines the routine for its solution, divides this routine into parts which can be performed by computers whose only talent is reliability without a trace of originality, and stands by to see that any defect in method or performance is rectified.

The analog of the mathematician in the case of such a factory is the "efficiency expert" of old disrepute who decides on the general pattern of work,

divides up the individual tasks, determines for each worker the sequence of motions and decisions which will accomplish these tasks most effectively, and stands by to see that his orders are fulfilled, and that in case of any error or inadequacy, they are modified in the proper sense. The employees of such a factory are even less skilled than the routine computer. They come to their work as whole human beings, but they are used only as effector organs of the superhuman mechanism with its brains elsewhere in the organizing staff. They eat and drink, love and hate, enjoy and tire, like other human beings, but from the point of view of their job alone, these outside faculties and necessities of their lives are nothing more than so much tare, so much useless baggage, perhaps inseparably connected with the pair of hands for which the employer pays, but of no direct value to him. Thus the question of replacing these workers by automatic machinery is not the question of replacing so many men, but rather half-men or quarter-men or even hundredth-men.

Under these conditions, the machine which performs tasks laid out without any regard for the psychological and sociological aspirations of man, could become a real competitor of the human worker. If the human worker is left only the rudiments of discretion in his choice of the method of performing his task, he is only the equivalent of the machine, and he is far too complicated and exacting a machine to compete with the glorified computing machine. In fact, the situation is just the same as that found in mechanical computation. At the low level of the repetitive tasks constituting the greater part of factory work, speed of performance and a high measure of unvarying accuracy are worth more than complexity. Thus, from the limited standpoint of expenses within the factory, automatic machinery is bound to encroach more and more on the individual workman.

From this fact it has become fashionable for purblind gadgeteers of a certain type to draw very false and dangerous conclusions. I have heard of an article soon to appear in a magazine belonging to a great syndicate of periodicals in which the claim is made that the machine is rendering the human being obsolete. This view is a grim reminder of errors of the past. It neglects the work of such management leaders as Gantt and the Gilbreths who long ago admonished business against a lack of "heart, sense, and feeling," and provided techniques which took cognizance of the potentiality and dignity of man's hands and, above all, of his brain. The ill-famed "efficiency expert" has given way to the professional motion-study engineer, and the slave-driving supervisor is replaced by professional managers.

The automatic factory, so much more complicated than any less mechanized industrial organization, demands managerial personnel who recognize their social responsibilities as well as their economic responsibilities. Today progressive management thinking denies that man himself is becoming obsolete wherever the machine supersedes him in the routine performance of routine tasks.

Behind this evaluation of the future of the machine lies an evaluation of man which, in my mind, is the sin against the Holy Ghost. Routine tasks lose all significance except in so far as they accomplish something for mankind: The railroad and steamboat exist to transport man and the materials necessary for his subsistence; the cotton field and textile factory to enable him to cover and shelter himself; the grist mill and wheat field to keep him from hunger.

Those who value man not in his own right but merely as an instrument for production see eye to eye with the slave merchant and the Egyptian gentleman who squanders at Monte Carlo the moneys earned by his fellahin in the

sweat of his brow. This evaluation of man is that of Fascism, of the attitude that I am one of the privileged élite, and that the common man exists for nothing but aggrandizement of this élite. Those who devaluate man in the presence of the superior efficiency of the machine, are simply those who have already devaluated man in their own hearts, and their works speak for them.

Those such as Samuel Butler, who have foreseen the triumph of the machine over mankind, have pointed to a very real danger, but often to one which they themselves have but imperfectly understood. They have made of the machine an independent and autonomous enemy of humanity, like the tiger that lies in wait for us, or the spirochete that rots our vitals. Yet the range of our enemies contains others which are in great measure the images of our own inner defects and inadequacies. The cancer cell is an intrinsic part of our bodies, flesh of our flesh, blood of our blood, bone of our bone, which represents an inner defect of our own construction, a demon already implicit in our own make-up. A virus may be a complete organism, an invader from the outside, but it may just as well be something like a gene, something between a chemical substance and a true organism, which can only reproduce itself by a perversion of our own metabolism, which renews the substance that has caused its perversion.

Thus the machine, for all the similarities that its functioning shows with that of the human organism, is at a much lower level of organization and complexity; and the dangers it offers to humanity are not those of an independent will and purpose of existence, but merely those of a material embodiment of our own stupidities and shortcomings. If we rate a man only as a factory hand, for the cost of his daily wages, then the machine will indeed displace man over much of his range of activity. But in essence, the factory hand is first a human being, and only secondarily a factory hand. In essence, production is merely a device to provide for consumption. Life is more important than toil, which has the primary function of providing the wherewithal for life. The danger of the machine is already implicit in the scorn of the self-appointed élite for the great body of humanity, which has expressed itself as Fascism, and may choose as a vehicle other forms of totalitarianism. It is this already existing ruthlessness which threatens to call the machine to its aid as an ally against the vast body of humanity and which in doing so threatens to cut off even its own reason for existence.

If we accept the primacy of man over his means of production, there is no reason why the age of the machine may not be one of the greatest flourishing of human prosperity and culture. Prima facie, plenty is a good thing, provided that it does not become a mere fetish like the potlatch feasts of the North Pacific Indians, and a mere vehicle for power, prestige, and ostentation. This does not mean, however, that this golden age of plenty will come without problems, and even dangers. Leisure must be recognized as a good thing, more especially in the opportunities it offers for a fuller life and a greater scope for the human urge to create. It must not be permitted, however, to degenerate into nothing but the universal distribution of *panem et circenses,* or bread and the prize fight, the cheap Hollywood movies, and the inspired twaddle that tends to invade all literature. Most of all, it seems that the routine work of the factory, although it exists primarily for the sake of the material products produced, does fulfill for certain persons a demand for the self-respect of useful employment, even as the jails fulfill for some persons the need of a sense of atonement.

However, to say that the automatization of industry may bring in its train social problems not easy of solution is

not to say that these problems are intrinsically not solvable except through the present factory system. The curse of Adam is old, but it has only exhibited itself for a century and a half or so against a background of wheels and pulleys. It represents a bankruptcy of imagination to say that it must forever show itself against the same background.

The forms of social organization are manifold. One experimental new form, that of orthodox totalitarian communism, is now under a great cloud in so far as the official and the popular attitude of the greater part of the Western world is concerned. This does not mean, however, that we are under any compulsion to fix the present practice of the Western world as something unquestionable and immutable. The chief revolution of the present time is not one of social dogmas, but of industrial techniques and practices. If we approach the difficult problems of the near future with our arms bound in a straitjacket, we shall perish, and we shall deserve to perish. Yet it is highly likely that with a little freedom of action, we shall find the future livable, and even full of hope.

THE LIFE OF A BUSHIPS ENGINEER

CAPTAIN ROBERT H. EMERICK, USNR

THE AUTHOR

in civil life, is a consulting mechanical engineer giving most of his attention to heating, air conditioning, refrigeration, and power plant design. His designs are functioning from Wisconsin to Florida, from South Carolina to California in the first named specialties, and in the power plant field, in Shanghai, China, Colombia and Chile, South America, as well as for various public utilities in the United States.

He has published two books, "Basic Refrigeration And Air Conditioning" (Prentice-Hall) and "Heating Design and Practice" (McGraw-Hill). Is currently writing "Power Plant Management" for McGraw-Hill under contract.

During the current fiscal year which began July 1, the Bureau of Ships will spend for shipbuilding and repair, about 2¼ billion dollars.

This is big business. The Bureau of Ships is one of the 10 biggest businesses in the United States. It is an engineering business, too, involving the design and repair of ships.

About 160,000 persons work under the cognizance of the Bureau of Ships. They work in our Shipyards, repair bases in Europe, Asia, Alaska, the Pacific Islands. Of these, about 1800 are engineering duty officers, 6500 are civilian engineers. Bureau of Ships engineers, military and civilian, are specialists in all the engineering fields, mechanical, electrical, civil, naval architecture.

Like everybody else, the Bureau of Ships is presently reported as being short of engineers. During the last war, we struggled against a similar shortage by training them on the job.

For instance, I'm a mechanical engineer. When I reported for duty at Pearl Harbor in 1941, my skipper said:

"What do you know about electricity?"

"Nothing," I said. "I can't tell a volt from an ampere."

"Fine," said my skipper, handing me a book on electricity. "Read this tonight and tomorrow I'll make you an electrical officer."

That's how I became an electrical engineer in no lessons and one night.

We might call it on the job training, concentrated.

Procedures are better today. Our younger engineering duty officers are given post graduate courses, extending from 1 to 2 years, at the best engineering schools in the country, like M.I.T., Columbia, Georgia Tech. We even send selected personnel abroad for special study in top foreign schools. The Bu-

reau of Ships insists that its engineers continue to learn.

Currently, efforts are being made to develop the younger civilian engineers. Senior engineers are impressed with the responsibility of teaching and guiding their subordinates. Professional classes are held after hours. Technical schools, convenient to Navy activities, are encouraged to organize special classes of value to Navy engineers. The Navy sometimes pays at least part of the tuition.

Incidentally, senior engineers are those with grades of GS-11 and up. In case you are interested, the top salary of a GS-11 is $6940; a GS-12, $8040; a GS-13, $9360. The grades go clear up to GS-18, at $14,800 a year.

At present, a captain in the Navy is about equivalent to a GS-14 in the pay scale. A GS-14 starts at $9600 and goes to $10,600. Nobody gets rich, of course, but nobody starves either.

We might observe also that the term "GS" means "general service" and not "go slow" as some people, including a few military folks, seem to think.

At present, electrical and electronic engineers are particularly in demand. Here is the reason for this need:

In World War I, we had no electronic equipment. In 1940, there were only seven radar sets in the Navy. Today, a war could not be fought successfully without effective radar aboard every ship we have.

These facts illustrate the magnitude of engineering growth in the last thirty years, particularly the growth in the last ten years. This growth must continue, or the Navy will become an obsolete buckler for defense. And the responsibility to avoid obsolescence rests substantially on engineers like ourselves, trained in some branch of naval technology.

BuShips engineers have every opportunity to try out their new ideas.

For instance, during the war, I rigged up an experimental air conditioning system for a destroyer. I designed it to use sea water for cooling. Unfortunately, my baffles did not work, and it poured sea water down the captain's neck as he sat in hopeful happiness at the wardroom table.

All my ideas have not come to such a disastrous end. Some have worked. The point is, ideas can be implemented—ideas are welcome.

Engineering duty officers, being engineering specialists, carry a great deal of behind-the-scenes responsibility. One of our jobs is to maintain the machinery of our ships and to repair that machinery when it breaks down or is damaged in battle. We are directly or indirectly involved in every sea battle that is fought, although our names seldom appear in the battle line-up.

Often our word sends a ship into battle, or keeps it out of battle. For instance, imagine yourself back in the year 1944. You are examining a section of condenser tube from the battleship *Tennessee*. Outside it looks good. But, the inside is marred by deep craters. Eventually, it will fail by developing a pinhole in the bottom of one of these craters.

Just before the Philippines Battle, the carrier *Princeton* came in with a moderate number of failed condenser tubes. They were like the *Tennessee* tubes. We could not tell for sure how many of the *Princeton's* tubes were in this foul condition. But, we could guess. The disease was epidemic. For safety, we felt the condenser should be retubed 100%. However, retubing would mean from ten days to two weeks, and the *Princeton* was needed now, the Philippines strike being in the making.

We had two choices. First, we could let her go, but if she broke down before, or during the battle, the blame certainly would be ours to bear. On the other hand, suppose her tubes were not

as bad as we thought, and because of her absence, we lost the battle?

It was a tough decision to make, and in the end, SerPac sent her out. The need was great enough to justify the risk.

We won the battle. The *Princeton* was sunk in the fight, but apparently her tubes held up to the last. The decision to send her, therefore, was correct.

Our decisions are not always so right. For instance, one afternoon, a young destroyer officer came into Pearl Harbor and this is what he said:

"Sir, coming in the harbor, the port engine began to pound. Then it stopped. I thought it needed more steam, so I opened the throttle. For a minute, it pounded terrifically, then stopped again. I thought it still needed steam, so I opened it full. It sounded like a boiler factory with nuts and bolts flying around inside. Everybody ran but me. I was too scared. Sir, what's wrong with it?"

"Son," I said, "you have no engine." It's full of turbine blades and nozzles. Tell your skipper he'll be here about five weeks. But, what did you do before you became a destroyer engineer, so called?"

He said, "I was a medical student."

This is another example of what I call wartime on-the-job training.

We opened his turbine, which should have been junk after such treatment, and there wasn't even a loose blade. The turbine was perfect.

His trouble was discovered to be a burned out thrust bearing. He had heard the thrust shoes chatter before they froze. My bad guess completely upset the operating schedule of that ship and for awhile, I was slightly mud with the Fleet.

As though worries over the machinery are not enough, BuShips engineers have money trouble. For instance, right now, we have a law that promises the jail to any officer who overobligates government funds. All I must do to go to jail is to authorize some shipyard to fix up a ship before I have the money.

You think keeping out of jail is easy? Here is an incident that can happen any day. It has happened to me.

My phone rings. It is a long distance call. Some operating agency of the Navy has a ship that needs repair. They are sending her to me.

"Where is the money?" I ask.

"Coming right up," says the voice from 500 miles away. "We'll send it by dispatch."

So, the ship comes in. Men commence to work on her because we know if the work is not completed during her availability, we might as well turn in our suits.

But the money does not arrive. I call my friend long distance.

"Look," I say, "the jail doors are yawning. Where is the money?"

"Sorry," he says. "The funds were spent on another job. It'll take a few days to get more."

Fortunately, this is not a regular occurrence. But, BuShips engineers really worry about money. We've got to—obviously. Our problem is to save the taxpayer's money, and at the same time provide adequate ship overhauls.

Unhappily, the Forces Afloat do not always hold BuShips engineers in the highest esteem. We sometimes are accused of being pedantic, dumb, stubborn, stingy, contrary, and just plain bureaucrats. Offtimes these accusations look pretty valid, but the point is, if each of us altered his ship to his heart's desire, we would have a Walt Disney kind of Navy, in which some units might sail only upside down, while others wouldn't sail at all. To my own desk, for example, have come proposals to relocate major machinery, and even to rebuild the ship's silhouette. One zealot suggested we cut up his carrier into three self-contained sections, so that if

one were damaged in battle, the other two could wriggle off safely, like a lizard shedding his tail.

These are extreme examples, of course, but even sensible requests must often be rejected if we are to obey the laws of uniformity and practice the conservation of funds. In these circumstances, sensible requesters may be justified at times in considering us very irritating people, indeed.

Recently, my office had to wrestle with a million-dollar contract, for ship activation in a private shipyard. We started the final negotiations with the contractor at 11 o'clock in the morning. For our ammunition, we had prepared estimated costs for every one of the more than 300 items of work. We required the contractor to do likewise, breaking down his estimates into labor, material, overhead and profit. We compared his estimates with ours. We argued man-hours and rates, overhead and profit. We went to the corner store and had sandwiches for lunch. We came back and argued. For supper, we had the sandwiches sent in. We argued while we ate. We reached an agreement at 11:30 that night. Details were finished at 12:30.

Both the contractor and ourselves were worn out, but the taxpayers were saved some money. Over $100,000, in fact.

The life of a BuShips engineer is not all work, worry, and meeting dates. Actually, we accumulate some very pleasant experiences.

For instance, one night in November of 1941, my family and I spent a quiet evening with a man and his wife that we had just met at dinner in the Halekulani Hotel in Honolulu.

As we parted, I said.

"Are you in business here?"

"Well, yes, in a way," he replied. "I'm in the Navy. I'm Vice Admiral Halsey."

When we installed air conditioning in the flag plot of the British carrier *Victorious*, they had never heard of air conditioning. They thought at the start we were telling them tall tales. The *Victorious* went off to battle with her officers sleeping in their shorts under a 55 F. blast from the unit coolers.

We shall always remember the *Victorious* kindly, for she departed with the opinion that BuShips engineers can perform miracles.

It is nice to be regarded so highly, but we know our limitations. Our job is to keep Navy ships fit to fight, at the lowest practical cost, and we spend our lives on that job, doing the best we can, promising no miracles, nor even 100% efficiency.

SCHEDULING OF WORK IN THE SHOPS

CAPTAIN R. E. W. HARRISON, USNR

THE AUTHOR

was born in Manchester, England, in 1893. Educated Manchester College of Technology. With Royal Engineers, British Army 1914-1919, Egypt, Gallipoli, Sinai, France, Belgium. Industrial Engineering experience includes special apprenticeship and supervisory positions with Churchill Machine Tool Company, England, in the building, design and engineering selling of precision grinding machinery; in 1926 as Director of Engineering, Cincinnati Grinders, Cincinnati Milling Machine Company; 1934 Chief, Machinery Division, U. S. Department of Commerce; 1935 Vice-President Chambersburg Engineering Company; in War II, on staff of Assistant Secretary U. S. Navy, and later as Special Assistant to the Under-Secretary. Registered Mechanical Engineer in Ohio, New York, Pennsylvania, Maryland and District of Columbia. Fellow, ASME and Royal Society of Arts; Member other Engineering Societies in USA and Europe. Present Duty, Industrial Engineer, Field Activities, BuShips.

The weight of the author's experience, as readily divulged by the record, lies in commercial industry and it is with the thought that experience in this field is to a major extent applicable in the Naval construction field this paper is offered.

In a Naval establishment it is a *sine quo non* just as it is in a commercial establishment, that the first principle which must be applied when an orderly accomplishment of work is desired is that this work must be planned in accordance with a step-by-step program, attached to which is a valid timetable.

There is only one major difficulty regularly encountered in the establishment of good scheduling, and that is the completely honest, mentally unreserved acceptance, by all hands concerned, that the program once devised is the "Bible," and that the timetable after finalization is *IT* for all hands. Industrial discipline in a well organized civilian plant is just as tight as military discipline, and while industry cannot fall back on a tight and adequate military law, it has, however, that terrible weapon instantly available, of depriving of his job, any man, from the president down to the last joined laborer or office boy. This can be done either with great consideration or great brutality. Everyone knows the situation, and of necessity, everyone accepts it. Wise managers very seldom use the extreme power which reposes in their hands, for the simple reason that if the power is used indiscriminately, it kills morale, and that end result is bad anyway. It means, in terms of this discussion, poor work output and a dishonored timetable.

This angle of industrial discipline has been dwelt upon at some length because it is of the very essence. Industrial discipline is an inescapable *must* in a Naval Shipyard, just as much as in private business, and while the methods of administration vary greatly between the two systems, each is aimed at obtaining a similar end product. The Shipyard Commander wants ships out on time with all work completed, and the private manufacturer wants motor cars, or gas stoves, or light bulbs, out on time and with an adequate profit certain in billings.

Industrial management has found that it pays rich dividends to let its team regularly know where it stands in the overall scheme of things and it is necessary to emphasize why the accuracy of scheduling is of such great importance in the overall well-being of this great nation.

As can be seen from the tabulation, as outlined below, the Naval Shipyard is Item *22* in a 24-Item Schedule. Failure on the part of Item *22* to deliver the goods on time can negate in wartime all the high powered thinking and planning which have gone into the previous 21 Items, and can so jeopardize Items 23 and 24 that the ship is late in joining the fight, it may never get into the fight, or it may arrive so late that the enemy has gained strength in the meantime, and the ship, the subject of Item *22*, is doomed before it gets into action.

THE OVERALL SCHEDULE

1. Aggressive idea, plus a man.
2. Meeting of Politboro.
3. Action by principal or satellite.
4. Report through channels to Joint Chiefs of Staff.
5. Discussion by J.C.S.
6. Navy gets word to get ready.
7. Discussion on how.
8. Establishment of ship characteristics.
9. Word to Chief of the Bureau of Ships.
10. Money.
11. Design.
12. Ship Type Desk, and word to all auxiliary services.
13. Contract to private builder or U.S. Naval Shipyard.
14. Schedule for building and arming the ship.
15. Completion.
16. Commission.
17. Assignment to a Fleet Commander.
18. Assignment of a special mission for the ship. (Sea trials and evaluations)
19. Duty on station.
20. Reports on performance.
21. Scheduling (overall) Naval Shipyard (by Department of the Navy)
22. Alterations and repairs at Naval Shipyard (Scheduling)
23. Reassignment.
24. A fight—to win.

Men's minds work in queer ways during peacetime and cold wars. Alert managers are devotees to the concept that when things go wrong, in this case when they get off schedule, it is the boss's fault for the simple reason that a single occasion cannot be recalled when, after giving the crew an outline of the overall situation, a specific program with clear instructions, plus a timetable, the crew has ever failed.

Few people realize their own necessary and vitally important contribution to their own country's strength and welfare, unless these same people are, from time to time, briefed on the real significance of their work.

Americans are intelligent people. A brief, concise and completely sincere,

overall briefing is all that is necessary to make working crews, for all times, conscious of the fact that their work on the program, and in accordance with the timetable, is a moral obligation which they cannot duck, and in fact, would never want to avoid.

One more word on this subject of *overall* scheduling. The availability of a ship for alterations, repairs, maintenance and overhaul, is a very carefully thought-out series of marks on the calendar, the details of which are worked out by the Chief of Naval Operations and the Bureau of Ships. The Chief of Naval Operations, of course, is the prime member of the team, knowing, as he does, *where* the ship power is needed and *when* it must be there. The Bureau of Ships, in collaboration with the Chief of Naval Operations, puts the dates on the calendar, which are *all* important in the overall scheme of things—internationally political — and economically practical.

In the preparation of overhaul schedules, representatives of the Chief of Naval Operations, the Commander of the Fleet, and the Bureau of Ships hold a scheduling conference. Yards are not consulted at this time because they are not posted on what new construction or conversions are planned for them. The information at this stage is unofficial and cannot be made available to one or all Yards until Congress has approved the program. Shipyards are consulted, of course, by the Fleet on changes and accommodations after overhaul schedules are issued.

All of the foregoing, can be summarized in the simple statement that Item 22 is supremely important, measured in terms of National Security—something far more immediately important than any other consideration which could be advanced at this or any other time.

RECORDS

Records—accurate records of time and work accomplishments—are all important. If an organization has none, these records must be created, kept up to date and used.

Production control, which is another name for intelligent scheduling, is just not what its name implies if there is no systematic records keeping, i.e., production is *not* under control when adequate records of past performances are not *immediately* available.

For simple, orderly housekeeping of records, a system of "classified" repairs is one good way of getting results.

Not every piece of machinery needs 100% repairs when a ship comes in for overhaul—some items of equipment need little more than inspection adjustment, testing and painting (while, at the other end of the scale, another piece of equipment may need complete replacement—by the Yard). Between these two extremes, there is the pump which needs a reboring or relining job, and a few minor bits and pieces—then assembly and test.

For the purpose of this record, take these three major classifications of types of repairs, as an example, and call the first one, Class A Repair; the second, Class B Repair; and third, Class C Repair. The railroads have followed this system for over one hundred years; it is simple; it makes for accurate bookkeeping; but the important thing it does in this instance is to build up a record of performances, against which can be computed an accurate forecast of time and money required to do a similar job in the future. If a railroad company had to plan and estimate in detail every repetitive job in the way of a diesel or

steam engine overhaul, the railroad would go broke in short order; and there is no apparent reason why a similar system of classified repairs would not work equally well in a Naval Shipyard.

Visualize a room surrounded by card racks, each space in each rack occupied by three cards, say, one red A Repair, one white B Repair, and one blue C Repair; each carrying the specification of a unit of work to be performed, plus the name of a piece of machinery to be overhauled.

After the arrival conference when the bill of particulars has been drawn, the planner and estimator retires to the P&E sanctum and starts pulling and stacking cards, each card in the properly selected classification for the overhaul in hand. The assembled cards, after careful check to see that all anticipated work has been covered, are then run through one of the IBM machines and answers start coming up, in terms of dollars and times. It is just as simple as that, but to be effective, it must be kept simple, and it has to be operated with *complete* integrity.

From the Naval Shipyard management's point of view, instead of every planning and estimating job being a one-shot expenditure which goes out of validation when the ship leaves the Yard, it becomes instead an investment paid into the bank or fund of knowledge possessed by that Yard, about the kind of work which that Yard is destined to perform at some certain future time.

This accurate information in terms of man days and dollars could, and undoubtedly should, be made available to the Bureau of Ships as basic data for use during discussions with the Chief of Naval Operations regarding length of availabilities. Likewise, the data, because of their easy accessibility and their accuracy, could be made available to a sister Naval Shipyard when, for some unavoidable reason, a ship has to be put into a different Yard for the same type of work as that normally done at the home Yard.

To return to the subject of scheduling, the only way in which schedules can be made to mean anything is if they are based on accurate records of past performance tempered by intelligent estimates covering whatever variables have crept into the situation in the meantime.

At times, in mechanical engineering design work, it is necessary to work with safety factors as low as 1.25 to 1, or 1.3 to 1, hence a wastage of human lives is the anticipated price for failure to calculate accurately the load-carrying capacity of this given mechanism. The day has gone forever when one could think of a number, double it and then add something to take care of the misfortune factor and hope to get away with it.

Under mobilization conditions tight schedules are invariably the order of the day, and while it has been possible to meet these tight schedules on occasion in the past by instant application of mass manpower, the odds are that this easy, simple formula will not be usable in future emergencies, and the onus is then automatically on management to accurately budget manhours or mandays in accordance with available records and experiences, not guesses.

There are many additional reasons why it is desirable that more accurate workscheduling be taken in hand now but only one will be dealt with at this point, i.e., economy in the use of funds. In the last analysis, everyone must inevitably face the day when a small pension or small income from some source is his only revenue, the size of this income being fixed and, of course, inadequate and far from equal to the support of the standard of living enjoyed today. Never should it be forgotten that every

penny of Government funds wasted makes it just so much more difficult to live when that day comes. In one generation, the purchasing power of the dollar has been cut to one-fourth of what it was, and people who formerly lived in comfort now live in penury on their small fixed incomes. There is no miraculous cure for this condition either creatable or remotely possible of accomplishment, hence, all concerned have a stake in every job—big or small —which comes into a Naval Shipyard.

The money which is *not* saved is later deducted from the purchasing power of retirement income. Economy in the use of Government funds is a personal and individual responsibility. Good scheduling, when done systematically, is the most potent weapon in securing this economy.

ELECTRONICS FOR DEFENSE AND INDUSTRY

ACKNOWLEDGMENT

This article, written by MR. E. W. ENGSTROM, Vice President in charge of the RCA Laboratories Division, Radio Corporation of America, was presented at the Eighth National Electronics Conference on September 29, 1952. It was published in the January 1953 edition of the "Journal of The Franklin Institute."

The theme for the National Electronics Conference a year ago was "Electronics for Defense." This year your officers chose the theme "Electronics for Defense and Industry," and it is on this subject that I now address you. I sincerely hope that your officers are prophetic in their choice of a progression of themes for succeeding conferences. I say this because this progression, if unchanged, would be as follows:

A year ago—Electronics for Defense

This year—Electronics for Defense and Industry

A future year—Electronics for Industry.

I am thinking, of course, of industry in a peacetime environment with the objective of direct benefits to mankind, for this is the ultimate objective; this is the motive that inspires.

There has just been concluded in this city a convocation commemorating the centennial of engineering in this country. Running throughout the reviews of technical accomplishments at that convocation was a common thread of thought. This common theme, no matter what field of engineering, stressed contributions towards living comforts, safety, security, and happiness. The speakers were confident that these gains would continue, that benefits would grow, that the whole of mankind would be the recipient of these advances.

We are now in the aftermath of World War II, a war that drew upon mobilized technology to an extent never before contemplated. We are currently in the midst of a defense program that is building more and more upon a foundation of science and technology. At the same time, we are advancing science and technology on an industry-wide front for peacetime purposes. And all the while we are trying to achieve a proper balance of effort between these objectives. One objective is preparatory defense to assure peace; the other objective is the enjoyment of that peace through the advance of man's comfort and position.

Thus, today, we are in an era of "defense and industry"—inseparable objectives in these times. Here, electronics has a key role of ever increasing importance. Out of each dollar now spent for national defense, approximately 10 cents go for electronics, communications and related items, a substantial increase over the electronics slice in World War II.

The Defense Department is expected to earmark more than 4 billion dollars for electronic equipment in 1952. This figure will be even higher if one adds other governmental investment in electronics to support the three services. This is quite an order for an industry that in 1940 grossed well under a billion dollars. Not only in volume but in adaptability, the industry has made an impressive showing. Production of military electronic items is now at a rate seven times that existing at the outbreak of the Korean war. And all but 5 percent of these items are of new and improved design. As an industry providing peacetime services, electronics now ranks with the leaders. In 1951, the public paid close to $5,000,000,000 for its products and services, including radio and television broadcasting.

Such activity, such expansion does not take place without adjustments. Let us scan, then, what I consider today's Number One problem in military electronics.

As new instruments and vehicles of war come into being, they are ever more complex. Electronics has grown from a simple means of contact and communication into the central nervous system of military might. More and more, electronics is assuming functions formerly performed by man's mind. This is a requirement of the increase in speed of military vehicles and carriers. Man's mind interprets vital data too slowly to keep track of many modern weapons and vehicles. The ultra speed of electronic detectors, computers, and controls is now mandatory.

Thus, military systems, which must be competitive with each other, grow more and more rapid in their operation. The reaction time becomes too fast for human operation and related factors become too numerous for rapid human comprehension. Thus electronics steps in to react, to interpret, to compute, to control, and finally, to take the place of man's senses and mind. The chains become longer, the systems more complex.

The men who operate and maintain this equipment have not changed, however. Because of electronics they are more powerful, but they, themselves, are not basically different from the man who drove the chariot or pulled the cross-bow.

Let's assume that this situation is represented by a triangle. The base of the triangle represents the man behind the anti-aircraft gun, the radar operator, or the jet pilot. This base we shall assume is unchanging in length. One leg constitutes the complexity of the system and this leg, as we know, has grown in length as the years, or even the months, have gone by. So far we have specified the base and one leg of the triangle. The base is relatively fixed—the human operator. The leg is varying in length and seemingly always becoming longer —the equipment complexity. Thus if we are to have a normal closed triangle, the other leg, which I have not so far defined, must grow in length with the complexity leg. What is this third leg of the triangle? It is the reliability factor of the equipment and system. If complexity increases, so must reliability in order to keep the triangle closed. The reliability leg must always keep up with the complexity leg if these weapons are to be of any service at all. The most ingenious circuit in the world is no good if the fighter plane that incorporates it fails on its way to meet its target.

All electronic engineers have a deep responsibility here. Let us keep in mind this simple triangle: operator, complexity, reliability. A useful result will be achieved only under the conditions of a closed triangle. Reliability, the leg that gives us the most concern, should be our major objective in military electronics.

Now let us have a brief look at today's Number One opportunity in peacetime electronics—television.

Immediately after the war, activity in extending commercial television gained great momentum. The 10,000 receivers in the public's hands at the close of the war quickly multiplied. Today, seven years later, there are more than 18,000,000 sets with an estimated audience of 60,000,000 persons. The number of stations on the air has grown from fewer than a dozen in 1946—and these offering only limited programs — to 110 serving 65 urban areas. By means of coaxial cable and radio relay the geographic spread of television programming has increased. Today we have expanding network facilities which span the continent. This has added strength and impetus to television.

At the beginning, just thirteen channels were provided for the service. These were in the very-high-frequency portion of the radio spectrum. The rapid growth of television broadcasting brought with it problems in the allocation of stations because of possible interference between them. This led to a review and there followed a "freeze" by the Federal Communications Commission on additional station assignments. The "freeze" began in September of 1948 and continued until a few months ago.

During this period, information and experience were accumulated on these interference problems. In addition, a system of slightly offsetting the frequencies of nearby stations on the same channels did much to eliminate or minimize a predominant source of interference.

The readily apparent need for more channels to achieve full coverage for television spurred fundamental studies on the ultra-high-frequency portion of the radio spectrum. A succession of propagation studies and field tests culminated in an extensive UHF set-up made by RCA-NBC at Bridgeport, Connecticut. Here tests were conducted under full-scale conditions and over a long period of time. First these were for basic studies of the system and later as a service to receiver designers.

With the practicality of UHF established and with technical considerations of VHF interference better understood and reduced, the Federal Communications Commission, in April of 1952, lifted the "freeze" on station construction. They announced the criteria for allocation of new VHF and UHF stations. By September, 1952, 60 new stations had been authorized.

This activity marks the start of the second big surge of television. The way has been opened for approximately 500 more stations in the VHF band and some 1500 stations in the UHF channels. The present skeleton of nationwide television service can be filled out. Virtually every community in the country will be within range of television broadcasts. A total of 50,000,000 television sets in the United States within five years is not an unreasonable estimate.

Added to this promise of growth for black-and-white television, is the opportunity for television in color. Extensive testing is under way. Experience is now building up in many segments of the industry. The National Television System Committee is active on the determination of signal standards. We may move forward with a compatible system permitting an orderly progression to television broadcasting enhanced by the addition of color. By compatible, I mean a color television system that can be received in black and white on conventional television receivers without modification.

Now let us take a look at a current promise for both military and peacetime electronics. This area of research—electronics in the solid state—is just now crossing the threshold into a revolutionary future. It is my Number One promise for electronics of tomorrow.

Radio equipment of the early days made use of essentially the same mate-

rials as its older brother, the electrical industry. These were the conductors—materials permitting the ready movement of electrons when under the proper influence; insulators—materials where the electrons are bound; and magnetic materials. From almost the beginning, however, a new class of materials entered the radio scene. These were neither conductors nor insulators in the usual sense and they did not obey Ohm's law. I refer to the loosely packed particles of the coherer and the crystal with its point contacts. These were the detectors of radio waves. While the performance of such units could be measured, the basis of the performance was little understood. Except for such specialty applications these semi-conductors were the discards of the electric and radio arts. They served well during the early radio days but passed from the stage when the electron tube emerged.

The electron tube became the lever-arm of radio and electronics. It is the keystone of all apparatus and techniques upon which the present ever-expanding industry depends.

While we have progressed far, and while we are still expanding the versatility and usefulness of electron tubes, attention again has been directed to the discard materials, the semi-conductors. As is so often the case, we find in the discard the real gem itself. By this time the approach was not through empirical experimetation but by painstaking research with understanding of each step. Also it was not a single approach but one which has taken many routes with many evidences of current and potential results.

The first broad uses of these materials came from their nonlinear and unilateral properties which were those of importance for radio-frequency detectors of the early days. Then we moved into small power applications as well. As understanding grew, we learned that conductivity could be influenced by radiant energy (photoconductivity), by electron bombardment (bombardment-induced conductivity), and by applied voltage (transitors), just as in the case for the electron tube. Here, however, we are working with the controlled action of electrons in solid materials.

Why is this important? It is important because we have a new tool, a new instrumentality. It promises to augment and to supplement the electron tube. It means new freedoms in the future in the designs of equipment. It means wider and added services and uses. It provides a new dimension.

We might well ask "Doesn't this spell obsolescence?" The answer is obviously "Yes," but it is the obsolescence which is the basis and the purpose of scientific research. It requires agile organizations and it spells greater service and utility.

It is in this area of electronics of solids—the use of semi-conductors—that electronics engineers have an immediate future task. It is clear that the foundation stones of our industry are to be modified and changed. This is the challenge. The job is to move in an orderly but aggressive fashion. The job is to be sure that the advances are constructive and beneficial.

I have outlined what I consider today's Number One problem in military electronics—reliability. We have discussed what I consider today's Number One opportunity in peacetime electronics—television. I have sketched what, in my opinion, is the Number One promise for electronics of tomorrow—electronics in the solid state. Shall we take one more step? Shall we attempt a glimpse at what, to me, seems to be the Number One promise for electronics the day after tomorrow?

I mentioned earlier that electronics, more and more, is assuming functions formerly performed by men's minds. Here today's elemental applications are prophetic for tomorrow and the day after tomorrow. In this area we face

a revolution of techniques, mechanisms, and machinery—a revolution as great if not greater than any that has gone before. I cannot emphasize this too strongly.

Electronics with its unlimited ability to count, remember, and control—electronics with its capacity for accuracy—electronics with its comprehensive coverage—electronics with its facility to operate tirelessly and without fatigue—is electronics literally asking to take over certain duties which have been performed by men's minds—thinking processes. What man can conceive, comprehend and perform, he will be able to construct in electronic systems to do his bidding and the electronic performance will be at least as effective as the human performance.

I am not just thinking here of helps to man such as he has developed to aid his senses, to aid him to compute, to aid him to store information or a variety of other helps. I am thinking of a synthesis of all these together with developments yet to come, so organized that by man's pre-arrangement the electronic system will sense, react, interpret, compute, act and control. It will do this using what is the equivalent of thinking and intelligence. It will do this because man has built these characteristics into the system. It will do this at man's simple choice to start or to stop. It will act with such speed and with such all-inclusive comprehension that it will outstrip man in its action. It will permit solution of the most complex of situations.

How far will this go? Certainly it will include thinking processes which are repetitive. Certainly it will "think through" and execute wherever situations can be pre-analyzed and stored in electronic memory. Maybe this will include situations which today would be considered as creative thinking or at least in the border area of the creative. This may be so for material improvements, and also in the realm of the scientific and the humanistic—for all the arts and sciences.

Where will this stop? I for one do not now predict. But let me express a feeling—it is no stronger than a feeling. Electronic performance does have a limit, but it is a limit which advances with the continual progress made by man in his development of techniques and systems. While this is certainly an expanding horizon, these advances are linked and limited to the progress of man himself. Man's mind has no limit in fundamental creative thought and thus will always remain supreme.

I have discussed selected matters relating to the theme for this conference—Electronics for Defense and Industry. In closing let us think for just a moment of matters basic to the environments we shall find ahead. As we move through the years which separate us from one National Electronics Conference to the next, all individuals and all groupings of individuals in the free world will add their respective contributions, defining and determining the complicated paths of defense and peace. May those paths be directed so as to move away from the acts or even the threats of war. For our part, in our great country, our actions to preserve and guarantee peace depend in no small part upon

1. The faith we carry in our hearts—that faith which we propose, if necessary, to defend.

2. The vision we carry in our hearts—that vision which inspires us to uphold our faith and which will inspire others because of the vision we display.

3. The fervor we carry in our hearts—that fervor which carries us in acting our faith—actions to assure the dignity and freedom of the individual.

Faith — Vision — Fervor

These we need more than we may think!

TECHNICAL PROGRESS IN MARINE ENGINEERING DURING 1952

ACKNOWLEDGMENT

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STEAM TURBINES AND BOILERS

Throughout the year, there appears to have been increasing interest shown in higher pressures, and particularly in higher temperatures, the lower range being 350/450 lb. per sq. in. at 700/750 deg. F.; the medium range, 550/650 lb. per sq. in. at 850 deg. F.; and the top range 850 lb. per sq. in. and over at 900 deg. F. and above.

Unfortunately, although quite understandably, there is little available information concerning one of the most interesting machinery installations, *viz.*, that of the quadruple-screw steamship *United States*. The machinery consists of naval-type steam turbines supplied with steam by eight all-welded boilers generating at 1,100/1,200 lb. per sq. in. (abs.) Engine-room and deck auxiliaries, with the exception of the cargo winches, are electrically-driven from a 440-volt A.C. supply.

An interesting paper read by Mr. W. H. Dickie, before a joint meeting of the Institution of Naval Architects and Institute of Marine Engineers, and entitled "High-powered Single-screw Cargo Liners," served to focus attention on this subject. The paper gave an account of the reasoning which led to the adoption of single-screw geared-turbine propulsion instead of twin-screw Diesel drive for a class of cargo liner, of 10,000 tons gross and 18 knots speed, requiring approximately 15,000 S.H.P. The author commented on the experience gained during the first few operating years. In the ensuing discussion, Mr. S. A. Smith added a valuable account of experiences with two similar ships, one having single-screw steam-turbine drive, and the other being equipped with twin screws driven by Diesel machinery. Trial results confirmed that a twin-screw vessel required more power at a given speed than the corresponding single-screw vessel, and the average figures over a period of two years showed the same tendency in service, the single-screw vessel being ⅝ knot faster than the twin-screw vessel. A comparison of repair and survey costs, over the same period, showed a 5 percent advantage for the steam installation.

Such large single-screw installations are now more usual than they were when the ships referred to in the foregoing were being considered, and there are many being built for British and Continental owners. It is probably the increased demand for such tonnage that has prompted so many oil-engine manufacturers to develop directly-coupled

supercharged engines capable of develcping upwards of 14,000 S.H.P.

The noted tendency towards everhigher temperatures leads to more arduous operating conditions for superheater and reheater tubes. The American Society of Mechanical Engineers have published the results of an investigation into the suitability of commercially available alloys, for use in such tubes, when subjected to a metal surface temperature of 1350 deg. F. and an internal pressure of 2000 lb. per sq. in. (abs.). An interim report indicated that materials having adequate mechanical properties are in reasonable supply, but the provision of materials with the necessary resistance to corrosion is much more difficult. It appears that the corrosiveness of flue gas is directly related to the sulphur, alkali and vanadium content of the fuel used. Under very corrosive conditions, all 14 alloys tested, were attacked; but under mildly corrosive conditions, a number of allows were found which withstood attack almost completely.

With the development of thermal and catalytic cracking, residuals are becoming progressively of a poorer quality, as they are left with a higher concentration of ash, vanadium and other objectionable matter. Commercial additives have been developed which prevent sludge formation and thus improve the performance of heating equipment and atomizers; but it is only when corrosion has been due to faulty atomization, causing poor combustion, that such additives can assist in reducing corrosion. As yet, there appears to be no additive which will eliminate slag and soot, and suppress corrosion due to vanadium attack.

Two papers have apeared, during the course of the past few months, on the subject of automatic combustion controls for marine boilers. One of these was by Mr. B. Taylor, B.Sc. (Eng.), read before the Institute of Marine Engineers in November, 1951, and the other, by Captain J. A. Hayes, U.S.N. (retd.), read before the American Society of Naval Architects and Marine Engineers. The two main objectives of automatic combustion control are to maintain a steady pressure under conditions of varying load, and to maintain efficient combustion at all firing rates within the range of the control, thereby maintaining the boiler efficiency at its optimum. Increasing use of such controls is being made; pneumatic systems are particularly favored, as compressed air is readily available in a ship, is safe, and can be easily stored and handled.

The range over which an automatic combustion control can act is directly related to the range of operation of the oil burners which it controls. For a simple burner of pressure-control type, with fixed orifice, this range is usually only from 100 percent to 65 percent. Börger suggests a burner in which the oil pressure is maintained constant, the full quantity passing through the atomizing device, but only the quantity required for combustion being admitted to the combustion chamber and the remainder by-passed. The range to be expected would be from 100 percent to 10 percent.

Mr. James F. Harvey, in a paper read before the American Society of Naval Engineers, discusses the use of steam-assisted atomization in order to increase the range of satisfactory burner operation. Steam atomizers were used for the initial successful attempts to burn fuel oil in ships' boilers, but, due to the continual drain on the boilers and consequent load on the evaporators, they were quickly replaced by the dynamic-pulverizer. Harvey's recent experiments show that a well-designed steam atomizer operates efficiently over a much wider range than the pure pressure-type atomizer. Set against the steam demand of a steam atomizer is the catalytic effect of steam in the oxidation of free carbon and virtual elimination of soot de-

posits from the heat-transfer surfaces, with consequent improvement of heat-transfer rates and reduction of steam consumption by soot-blowers.

The performance of an oil-burner is considerably influenced by the viscosity of the fuel delivered to it; and one of the difficulties of successfully burning the large variety of fuels which are encountered, under the description of "Bunker C," at the various bunkering stations, is in arranging for the correct amount of feed heating to give the required viscosity for correct automization. To meet the problem, an interesting device has been developed, which continually measures and indicates the viscosity of the oil at the heater discharge. If required, the instrument can be arranged to control, automatically, the steam supply to the heater, and thus maintain the viscosity at any value.

The air preheater, at the back-end of the gas path, is particularly prone to sooting-up under conditions of imperfect combustion, and to corrosion attack if the fuel contains any appreciable proportion of sulphur. The search for greater boiler efficiency tends to accentuate the latter effect. With this in mind, several boilermakers have recently proposed the abolition of the gas air-heater and its replacement by a bled-steam air-heater (and economizer, if not already fitted). A stimulating paper on this subject was read by Mr. W. J. S. Glass, in November last, before the Institute of Marine Engineers. For steam conditions of 600 lb. per sq. in. (abs.) at 800 deg. F. and above, the advantage of the gas air-heater over the steam air-heater on a theoretical basis is something of the order of ½ percent—an amount that is considerably overshadowed by the practical considerations of freedom from trouble, maintenance and flexibility.

At the Corby Works of Messrs. Stewarts and Lloyds, Ltd., an electric resistance welding process is being used to produce steel tubing between 1-in. and 4-in. diameter. The tube thus produced is reported to be in every way comparable with cold-drawn seamless-steel tubes, but is considerably cheaper. Where ductility is particularly important, as in boiler or superheater tubes, the tubing is normalized after welding.

Investigations with the object of improving refractories and brick bolt materials are being actively pursued by the British Shipbuilding Research Association, in conjunction with the British Ceramics Research Association. A survey of existing service conditions is being made, and laboratory tests on the resistance of firebrick quarl bricks begun.

In connection with steam-piping materials, for use with advanced steam conditions, the paper read by Mr. D. W. Crancher, B.Sc., before the Institute of Marine Engineers, described the properties of four available steels which cover a range of temperatures up to 1050 deg. F. They are plain carbon steel, and three low-alloy steels containing molybdenum, chromium and vanadium. Information on the influence of aluminum and of various heat-treatments on the creep properties of low-carbon steels can be found in the paper on this subject presented before the North-East Coast Institution of Engineers and Shipbuilders, by Mr. D. C. Herbert, B.Sc. (Eng.), and Mr. E. A. Jenkinson, M.Sc. (Eng.) If a mild steel has been normalized, and if not more than ½ lb. aluminum per ton has been used in its de-oxidation, then it should be suitable for use up to 850 deg. F. surface temperature.

Many articles have appeared in the technical Press, and considerable interest has been shown, in connection with the development and use of chemical means for the cleaning and descaling of heat-transfer surfaces in boilers, economizers and oil-heaters, when mechanical means are impossible or undesirable. Acid cleaning has become possible and

popular due to the development of inhibitors, which, under properly controlled conditions, permit removal of scale deposits and prevent attack on the parent metal. The base of such cleaning fluids is often a weak solution of hydrochloric acid, to which may be added various inhibitors, wetting agents and special additives to meet particular scales. There are also available various detergent solutions for freeing surfaces of oily deposits. The acid-base cleaning solutions must be handled with proper precautions, as hydrogen is usually evolved during the attack on the scale, and must be collected and led harmlessly away. It must also be remembered that particular inhibitors will probably only be effective in protecting one named tube material.

The Velox-boiler installation in the French passenger vessel *Ville-de-Tunis,* to which reference was made in our 1952 review, is now in operation; and as the owners have a similar ship in their fleet equipped with more normal-type boilers, an analyses of running experiences and operating costs of the two ships should have considerable value. In passing, it is interesting to note that, in designing and building a turbine driven by exhaust gas for operating their compressor, the Velox engineers had unwittingly built the first successful continuous-combustion gas turbine. Prior to that date, most of the effort in gas-turbine development had been in the direction of the explosion gas turbine; but, while carrying out tests on the first Velox boiler, Stodola realized the significance of the exhaust-gas driven turbine, and, thereafter, the continuous combustion type of turbine became established.

RECIPROCATING STEAM ENGINES

There is continued demand for the N.E.M. reheated reciprocating engine, and for combination sets of triple-expansion engines and Bauer-Wach exhaust-steam turbines. Of more interest to marine engineers, however, will be the outcome of the trials of the combination set of N.E.M. reheated engine and Bauer-Wach exhaust turbine, which, as reported in 1952, is being supplied for a vessel ordered from Messrs. William Pickersgill & Sons, Ltd., of Sunderland, to the order of Messrs. H. Hogarth & Sons, Ltd., of Glasgow.

DIESEL MACHINERY

The main trends in oil-engine development during the past year appear to be principally twofold. Firstly, increasing interest has been shown in the use of heavier grades of fuel, both for slow and medium-speed engines, where the difficulties of using an oil with an increasing proportion of residuals are of a character different from those experienced when burning residual oils in boilers or gas-turbine combustion chambers. Secondly, the number of supercharged two-stroke cycle engines has increased.

For some time now, the steady rise in operating costs of motor vessels has directed attention to the use of cheaper grades of fuel in directly-coupled main engines, and ideally, in order to save bunkering two different qualities of oil, the auxiliary machinery should burn the same type of fuel as the main machinery. Mr. C. D. Brewer, in a paper on "Fuels for Use in Marine Auxiliary Oil Engines," read before the Institute of Marine Engineers, discusses several problems raised when using heavier oils in auxiliary engines. Mr. J. R. P.

Smith's paper, entitled "The Use of Heavy Fuels for Medium-sized Marine and Stationary Diesel Engines," read before the Institution of Mechanical Engineers, also discusses much the same problems.

The conclusion to be drawn from laboratory experiments and from operating records is that, while fuel characteristics have but little effect on the thermal efficiency of an engine, they have a marked effect on reliability and maintenance requirements. Furthermore, the large slow-speed machine proves to be less fuel-sensitive than the smaller medium-speed engine.

In choosing a common fuel, for both main-engine and auxiliary use, a compromise must, therefore, be made, and Mr. Brewer reviews the more important factors which will influence the choice. The choice may be widened by the use in auxiliary machinery of supercharging, chromium-plating of cylinder bores or piston rings, and additive-type lubricants.

The results of work done in the United States of America on wear rates, by using a radioactive tracer technique, have been published by Jackson and others in the Transactions of the Automotive Engineers. It is found that, for the medium and high-speed engines they were testing, the rate of wear was greatly influenced by the sulphur content of the fuel (irrespective of source) and by the liner temperature, higher temperatures reducing wear. Such an elevated temperature can be maintained by circulating the cooling water against a static head of about 10-15 lb. per sq. in. (gage). Experiments have also demonstrated that additives of calcium nitrate and zinc nitrate to a 0.7 percent sulphur fuel have reduced ring wear. Addition of 0.0034 percent calcium nitrate reduced ring wear by 11 percent; addition of 0.022 percent reduced it by 30 to 50 percent; while addition of 0.0315 zinc nitrate reduced wear by 21 percent.

The well-established Stork double-acting, two-stroke cycle engine is now regularly being fitted with liners chromium-plated on the Van der Horst process, and operational results have demonstrated a marked reduction of wear rate. A worn liner can be successfully stripped and replated. The trial chromium-plated liner fitted in the Werkspoor single-acting, four-stroke cycle Diesel engine of the *Auricula* has also shown a marked reduction of wear rate, being only 0.026 mm. per 1000 hours or about one-fifth that of a standard liner. This vessel had completed over 33,000 hours' running at full power by April, 1952, and averaged 4120 I.H.P. on boiler oils ranging in viscosity between 1200 and 3000 secs. Redwood No. 1, at 100 deg. F. Wear rates and reliability have been normal, and the expectations of the initial experiments have been fully borne out. The fuel consumption has been 18,212 tons in 5½ years' trading and the estimated saving of fuel costs is £61,000.

Considerable developments are taking place in connection with two-stroke cycle machinery; and, in an endeavor to gain precise information concerning the scavenging process in such machinery under varying conditions, the British Shipbuilding Research Assocation have had built two experimental single-cylinder, opposed-piston oil engines, the preliminary trials of which have been commenced. Meantime, in conjunction with Messrs. Ricardo & Co. (Engineers), 1927, Ltd., of London, the Association has developed a modified Farnboro electric indicator, capable of recording the low-pressure phenomena which occur in engine cylinders during exhaust and scavenging periods.

Even though there is little enough data of a reliable nature, manufacturers are pressing on in an endeavor to establish the supercharged two-stroke cycle

engine. Following successful development work, Messrs. Burmeister and Wain, of Copenhagen, have adapted a large two-stroke cycle, six-cylinder Diesel engine for exhaust turbo-charging. The engine is a uniflow-scavenged poppet-valve engine of a normal type, and due to turbo-charging, the power delivered at 115 r.p.m. is increased from 5530 S.H.P. to 7500 S.H.P., while the specific fuel consumption is slightly reduced.

Messrs. William Doxford & Sons, Ltd., of Sunderland have reported that their experimental three-cylinder turbo-charged oil engine had delivered an increase in power of 50 percent at 0.34 lb. per S.H.P.-hour, while an increase of 25 percent was delivered at 0.325 lb. per S.H.P.-hour.

The usual method of driving exhaust-gas turbo-blowers is to exhaust each cylinder into a common manifold, and to lead the gas into a single turbine. This arrangement involves certain losses of pressure, temperature and kinetic energy in the exhaust gas and also permits of interference of one cylinder with another. In order to reduce such losses, and to obtain a maximum utilization of exhaust-gas energy, the Holzwarth Gasturbinen Company have developed a turbine into which each cylinder discharges its own exhaust gas through its own pipe and nozzle. The gas paths are kept as short and direct as possible; and although such a system is, at present, only applied to medium and high-speed machinery, it is of considerable interest.

The success of the M.A.N. experimental highly supercharged engine, referred to in the 1952 review, when an M.E.P. of 228 lb. per sq. in. was developed, with a specific fuel consumption of 0.31 lb./S.H.P.-hour, has encouraged the firm to build a prototype highly supercharged engine with larger cylinders and intended for marine propulsion.

A paper read by Mr. John Lamb, O.B.E., in April last, before the Institution of Mechanical Engineers, on the subject of "Explosions in Enclosed Crankcases of Steam and Internal-combustion Engines—their Cause, Effect and Possible Remedy," takes the attack on this problem a step further. The investigations reported have been carried out on an experimental rig and also on an actual engine, which has already suffered two crankcase explosions. The work is still continuing. The paper clearly draws attention to the wide difference between the requirements of Lloyd's Register of Shipping and the American Bureau of Shipping concerning ratio of area of safety-escape devices to cubic capacity of crankcase. It is to be hoped that an adequate value for this important ratio will soon be agreed upon.

Messrs. Crossley Brothers, Ltd., of Openshaw, Manchester, are fitting an interesting type of crankcase relief valve to their engines of 10¼-in. cylinder bore and upwards. It consists of a very light flat plate which deforms under a small pressure, thus permitting escape of gas. Closure is rapidly effected by the elastic force due to distortion. So light are the valves that they continually chatter with the pulsations of a normally running engine; and it is considered that, in the event of a hot spot developing, such continual movement will result in the emergence of sufficient smoke to give warning of heat generation.

Another device for suppressing explosions is based on the system used to protect aircraft gasoline tanks. A double diaphragm detector, arranged to respond to a predetermined rate of pressure rise, controls the influx of a suppressing fluid, which is introduced as a mist at speeds of 300 ft. per second. This speed is considered to be greater than the initial speed of advance of a hydrocarbon flame front.

In a laudable endeavor to reduce complication, several developments have oc-

curred in connection with fuel-injection systems. Mr. P. Jackson, M.Sc., in a paper on "Fuel-injection Systems for Large Marine Engines," read before the North-East Coast Institution of Engineers and Shipbuilders, in February last, gives a short review of commonly used injection systems, together with an account of some research work, which resulted in the development of pneumatic and hydraulic accumulator pumps for use with the Doxford oil engine. Such pumps appear to combine the advantages of the common rail and jerk-pump systems, together with the added virtue of simplicity. In the case of the motorship *Alcinous* (Blue Funnel Line), the Kincaid-Harland-B. & W. single-acting, two-stroke cycle, seven-cylinder Diesel engine (7000-7200 B.H.P. at 107 r.p.m.) has been fitted with the Archaouloff injection system, the fuel pumps being operated by gas passing from the engine cylinders. As the gas-pump/fuel-pump unit cannot meter the fuel, power control is effected by a main fuel pump, which meters the fuel to the injection pumps. It is reported that, during the maiden voyage of this vessel, the machinery showed good maneuverability and was noticeably quiet in operation.

The oil-tank motorship *London Splendour,* of 24,700 tons deadweight, and powered by a Wallsend-Doxford 6800-S.H.P. engine, is interesting in that there is a main-engine chain drive to three service pumps, requiring a total of 136 H.P. The pumps are of positive screw-displacement type, and run at 740 r.p.m. Apart from the mechanical losses in the drive, the power required is supplied at the same specific fuel consumption as the main engine. This is equivalent to about ½ ton of main-engine fuel per day; whereas, if driven by independent steam engines, the equivalent fuel consumption would be 4 tons of boiler fuel per day, or, if electrically driven, the equivalent would be 1 ton of Diesel fuel per day. Steam for lighting and other services is raised by a waste-heat boiler, so that, while at sea, only the main-engine fuel is being consumed.

GAS TURBINES

The gas-turbine set which is installed in the Anglo-Saxon Company's motorship *Auris* has now completed over a year's satisfactory, trouble-free running, and it promises well to fulfill the initial expectations. The ¾-in. diameter tubes in the heat-exchanger have been an undoubted success, and cleaning them has become a completely routine matter which is entrusted to the donkeyman. The 1000-kW. gas-turbine alternator set, on test by Messrs. W. H. Allen, Sons & Co., Ltd., of Bedford, has now also completed well over 1000 hours of running, and has confirmed its ability to meet sudden changes of load without appreciable variations in speed. Initial tests have been commenced on the Pametrada marine gas turbine, the output being 3532 H.P. at 4650 r.p.m., with the h.-p. turbine inlet temperature of 1242 deg. F., the l.-p. turbine inlet temperature 1284 deg. F., and the average fuel consumption being 0.505 lb./S.H.P.-hour, corresponding to a thermal efficiency of 27.9 percent.

In the cases of both the *Auris* and Allen installations, most of the development work during the past year has been in connection with the endeavor to get a burner with a wide range of discharge rate, which will run for periods of the order of 500 to 1000 hours without attention. The adjustment of burners in a gas-turbine combustion chamber is of such critical importance that the normal boiler practice of cleaning and changing burners every watch cannot be tolerated. When developed, the long-life burner may well be adapted for boiler use.

The troubles mentioned in connection with the combustion of residual fuels in boilers are even more acutely present in connection with gas turbines. Full use of residuals awaits the development of more corrosion-resistant materials for blades and nozzles, or additives which will reduce corrosion attack from combustion products containing alkali, vanadium and sulphur.

Gas turbines of a quite different type are being fitted in two small vessels for French owners. They are, in effect, exhaust-gas turbines, and each propulsion unit comprises two turbines which are driven by the exhaust products of two free-piston generators. Each generator is driven by a centrally placed opposed-piston unit; to each piston is attached a compressor element, the assembly in effect forming a single-line, two-stroke cycle, opposed-piston engine without a crankshaft, and having a compressor at each end. The compressor ends supply the scavenging air, and the whole unit will work against a back pressure of 43/45 lb. per sq. in. (gage), with an exhaust temperature of 840/930 deg. F. The exhaust products are supplied without further reheat to the turbine.

GEARS

A stimulating paper on "Epicyclic Gears" was read before the Institute of Marine Engineers, in March last, by Mr. T. P. Jones and Mr. H. N. G. Allen, M.A. Beside the many applications of such gears to medium and low-power transmission for winches, fans, blowers and compressors, definite proposals were put forward for a reverse-reduction gear, capable of transmitting 10,000 S.H.P. and reducing from 4500 r.p.m. to 110 r.p.m. The adoption of such a gear for coupling gas-turbine machinery to a propeller shaft may provide an attractive alternative to the use of electric drive or reversible-pitch propellers.

With the object of obtaining lighter, more compact and more efficient ship-propulsion gears without sacrificing reliability, the American Naval Boiler and Turbine Laboratory have been continuing a series of tests on standard destroyer-escort gears, built to the specification required during the Second World War. The gears are tested in pairs, being loaded with a mutually applied torque by means of back-to-back coupling. The first pair tested, taken straight from Navy stock, were worked up to 300 percent full-load by the 1100th hour and failure occurred 500 hours later. After additional processing, a second pair tested, successfully carried 450 percent full-load before failing. It is considered that advancement of design, by using higher loads than at present, will not jeopardize reliability, but, rather, will tend to improve it, as reduction in size will reduce susceptibility to misalignment due to hull and shafting distortion when in a seaway.

MISCELLANEOUS

Shafting Failures—

Following the attention which has been given to tailshaft failures over the past several years, an exhaustive investigation has been initiated by the Ships' Machinery Committee of the American Society of Naval Architects and Marine Engineers, and it is being carried out jointly by the U.S. Navy and the Society. The T-2 tanker, U.S.N.S. *Mission San Luis Obispo,* was selected for full-scale tests, and was fitted with a new tail shaft, having the

necessary instrumentation to record torsional and bending strains just forward of the propeller hub. The shafting was vibrated when at rest by means of a vibration generator, attached to a propeller blade, both in dry-dock and when water-borne. Strains were also measured at sea for a variety of trims, and under arduous conditions of accelerating r.p.m. and steering. No extraordinarily high strains were recorded, but bending stresses due to "whirling" of the overhanging propeller were of the order of ± 4000 lb. per sq. in.

Dehumidification—

In a paper entitled "Moisture Damage to Cargoes," read by Mr. W. McClimont, B.Sc., before the North-East Coast Institution of Engineers and Shipbuilders, early in 1952, a survey was given of the extent of moisture damage to cargoes and its effect on relations between shipowner and shipper. The proportion of cargoes found to be so damaged was only very small; but with a return to increased competition for freights, and more normal trading conditions, considerations of goodwill and prestige will encourage the increased use of mechanical ventilation and drying systems. In the problem of hold ventilation, as in the case of many others, an all-embracing standard cannot be laid down, but each trade will require its own particular conditions. The author presented data having specific reference to the requirements necessary for the efficient sea carriage of natural textile fibers, rice, fresh fruits and tobacco.

The adverse effects on personnel and cargo are two of the problems raised by humid environmental conditions; yet another is the effect on supports and insulation surrounding refrigerated spaces. In this connection, almost all post-war German refrigerated ships have been fitted with a dehydrating plant, which withdraws moisture-laden air from the refrigerated spaces, then dries and returns it.

During the past few months, results have been published of a series of tests carried out on the maiden voyage of one such vessel—the motorship *Proteus*—while carrying bananas. It was estimated that about 80 percent of the moisture removed by the dehydrating plant originated in the insulation, and that, in the absence of drying plant, the rate of water condensation in insulated spaces would have been about 0.12 lb. per cu. ft. per annum. Remembering that bananas are usually carried at a space temperature of 55 deg. F., considerably heavier condensation rates may be expected in the insulated spaces surrounding frozen-meat chambers. Such rates of moisture collection, if unchecked, could cause considerable damage to supports and insulation.

An increasing interest is being shown in the use of air-drying plant, for protecting oil-tank ships from internal corrosion. From the results of his work on "The Corrosion of Steel by Sea-salt of a given Moisture Content," which was published in the Journal of the Society of Chemical Industry (1950), Mr. S. J. Duly showed that (*a*) corrosion of mild steel by deposited sea-salts is governed by their moisture content; (*b*) the moisture content is considerably controlled by the relative humidity of the ambient air; and (*c*) at 75 deg. F., the rate of attack is slowed to almost negligible proportion if the moisture content of the salts is kept below 8 percent. When mild steel is exposed to sea-water, the rate of attack is principally controlled by the availability of dissolved oxygen for depolarizing the cathodic areas, thus preventing the self-stifling of the electro-chemical reaction, and allowing corrosion to proceed unhindered.

Consideration of these two points leads to the conclusion that, in order to reduce corrosion when the cargo spaces

of oil-tank vessels are carrying sea-water, such spaces should be *completely* filled with water, so that no free surface exists at which oxygen can be dissolved. In such circumstances, attack is quickly stifled, due to lack of oxygen. Furthermore, when a tank previously filled with sea-water is allowed to stand empty, it follows that the surfaces should be dried out as quickly as possible, and that the relative humidity of the ambient air should be reduced to a value which would not allow the moisture of the salts deposited during drying-out to exceed 8 percent.

These principles have been applied in the case of several vessels, notably the steamship *Petersburg* (the first full-scale pilot experiment) and the motor-ship *British Warrior*. The success achieved in these vessels in reducing cargo-tank corrosion has led to the placing of orders for air-drying machinery with Cargocaire, Ltd., for at least 10 tank vessels of British and Continental registry.

STRUCTURAL BEHAVIOR IN SHIPS

BY CAPTAIN E. A. WRIGHT, USN AND MR. JOHN VASTA

DISCUSSION

BY COMMANDER J. A. BROWN, USN

OF THE ARTICLE

Reading the article on "Structural Behavior in Ships at Sea" in the November, 1952, issue of the Journal of this Society, proved to be a stimulating experience for me. As I read the article, I found myself disagreeing with some of the statements and conclusions of the paper. I was, therefore, stimulated first to look up and read most of the papers listed in the Bibliography of this paper. After studying the more significant of these papers, I was further stimulated into writing this discussion.

One thing which is emphasized by this article is the great paucity of reliable information on structural behavior of ships in a seaway. The authors list but 12 ships as having been observed during the last fifty years. This is indeed a small number of ships to serve as the only scientific attempts to correlate the calculated stress with observed stress in ships' structures.

To these tests listed by the authors I believe that the following are of significance and should be added to this listing.

Year	*Ship*	*Country*
1926[1].	*San Fraterno* *San Tirso*	England
1935-36[2].	*Beaverbrae*	England
1937[3].	*San Conrado*	England

For the S.S. *San Fraterno* a still water stress of 4.45 tons/sq. in. was determined. During a 20-day voyage from Florida to England the following stresses were observed:

On 2 days the half range of stress exceeded 5 tons/in^2 which, combined with still water stress of 4.45 tons/in^2, gave an aggregate stress of almost 10 tons/in^2.

On 1 day the half range exceeded 4 tons/in^2 with total stress between 8 and 9 tons/in^2.

On 7 days the half range exceeded 3 tons/in^2 giving a total stress greater than 7 tons/in^2.

On the S.S. *Beaverbrae,* Mr. Stocks found that the ratio of maximum stress range to mean stress range varied from about 2.5 to 3.0. This occurred even for waves of about one-half the length of the ship, and even though the ship was slowed to 8.5 knots to prevent pounding. On certain occasions with beam seas, the stress range was 4.9 tons/in^2 and with seas ahead the range was 5.0 tons/in^2. The angles of pitch were about 7 degrees for these two cases, although the maximum roll in the former case was 17.5° as compared to 6.5° in the latter. With following seas the stresses were less than 1 ton/in^2.

Since the sea conditions were different, these are not strictly comparable, but they do indicate that high stresses can occur even though the waves are nearly abeam. They also indicate that stresses will be low running before the seas. This paper clearly shows the great effect that variations in loading have on the value of the stress induced in a ship girder. The greatest absolute value of stress obtained on the *Beaverbrae* occurred when the hogging stress in still water was a maximum due to the loading of the ship's cargo. This was true, even though the effect of the waves was appreciably less than the maximum observed. Mr. Stocks also states "If speed had not been reduced, the peak fluctuations and, therefore, maximum range would have been increased without materially affecting the mean range, thereby to show still higher ratio of maximum to mean range." In other words, increasing the relative speed of ship to wave will increase the peak stress even though it may not greatly affect the mean value of stress.

The data on the *San Conrado,* recorded by Mr. Bridge, also indicated that the maximum stress over a given period of time exceeded the mean stress by as much as fourfold even though the sea conditions remained constant. This occurred for waves varying from 180 to 250 feet in length and from 10 to 16 feet in height. The length of the ship was 460 feet. This maximum ratio occurred with the ship heading into the seas, whereas the minimum ratio of 1.6 occurred when running before the seas. Stresses of moderate intensity occurred with the seas practically on the beam.

Further information on the *Ocean Vulcan* tests is given in a paper entitled "Longitudinal Strength—A Review of Some Recent Developments" by James Turnbull, presented before the Institute of Naval Architecture, 1952. An abstract of this paper was published in the Shipbuilding and Shipping Record, October 2, 1952.

For the usual cargo type ship the *Ocean Vulcan* tests indicate that the important stresses are those due to vertical bending, axial compression, and slamming. Torsion and horizontal bending stresses were not significant.

In addition to being impressed by the fact that there are relatively few recorded tests on the behavior of ship structures in a seaway, the student is apt to become confused by the manner in which the data are recorded. For instance, in the description of the tests on the *Ancon* and *Faith,* as given in reference (10), the authors record only strain variation due to wave action. The stress due to the initial loading of the ship in still water is ignored. No data regarding the actual maximum stress can be deduced from these tests, although the variation due to waves was given as about 3.6 tons/in^2.

Likewise, in references (11) and (12) the estimated maximum bending moments on the *Cuyama* of 140,000 ft. tons in sag and 210,000 ft. tons in hog were due to the wave action alone. To get the true value of stress in the *Cuyama* one must add to these values a still water bending moment of 120,000 ft. tons in sag. The net bending moments are, therefore, 260,000 ft. tons in sag and 90,000 ft. tons in hog. The variations in bending, as the *Cuyama* was poised first on the crest and then on the trough of a wave, show that the former has the greater effect, but this does not result in the maximum stress in the hull structure. The true maximum stress in the *Cuyama* occurred during sagging which is to be expected for tankers. This is substantiated by McDonald & MacNaught in their paper in the Trans. Society Naval Architecture & Marine Engineers, Vol. 57, 1949. Likewise, in discussing the strength of tankers in Principles of Naval Architecture, Volume I, Donald Arnott states "It will be found, however, that the critical condition for the loaded vessel with machinery aft will be that of sag-

ging." Careful analysis of Roop's data reveals that the highest measured bending moments were only 73,000 ft. tons in hog and 56,000 ft. tons in sag. The higher figures of 210,000 and 140,000 were "deduced" from these figures by processes which are open to some question.

Similarly, one finds from reference (15) that the maximum measured strains gave greater bending moments in sagging than hogging. But when we add the strains due to still water effect, the net strain is approximately four times greater in hogging than sagging. This is the general condition for ships with machinery amidships and is generally true for cargo carriers, ocean liners, and even warships, such as aircraft carriers, which do not carry large concentrated weights near amidships to overcome the excess of buoyancy usually present in this area.

Another significant feature of the *San Francisco* tests is the decrease in sagging stress which occurs when running before the seas. The impact loadings on the bow are avoided and the stresses are apparently further reduced by the decrease in relative velocity between the ship and the wave. This was also found to be the case in the investigations of the *Cuyama*. Under these conditions, hogging effects of the wave may exceed those due to sagging.

It appears, therefore, that for wave action alone higher bending moments occur when the wave crests are at the ends of the ship, particularly if the ship is heading into the seas. But we must not forget that when this bending moment must be added to that due to the still water effect, for tankers and ships with machinery aft the still water effect usually causes the maximum combined bending to occur in sagging. Generally for cargo ships with machinery near amidships, the maximum combined bending moment will occur with the wave crest amidships. Emphasis should not be placed, therefore, on the strength of decks in compression and the strength of the bottom in tension for most ships. In fact, the ideal solution for most ships would be to design the strength of both the decks and bottoms of ships to be equally effective in tension and compression. In any case, both the deck and shell plating should be adequately supported against buckling. Under Tentative Conclusions, Item "c" is correct only if it applies specifically to the additional stresses induced in the ship's structure due to the wave alone ignoring still water loading. This conclusion is also more valid when heading into the seas than when running before the seas.

Item "e" under Tentative Conclusions states, "In combined pitching and rolling, as when crossing the seas obliquely, stresses are very much less than those in pitching only." This is undoubtedly true for most ships, but more data must be collected before it can be accepted as being applicable to all ships. Long, slender ships such as destroyers and light cruisers are probably exceptions to this conclusion. For instance, in way of the machinery spaces, a destroyer hull consists of but the outer envelope supported by transverse bulkheads and 2 or 3 intermediate transverse web frames with no inner bottom or second deck. In order to save weight, scantlings are reduced to a minimum. In addition to this inherent lack of rigidity, the destroyer has several large concentrated weights located well above the axis of roll. These include the gun mounts, torpedo tubes, directors and superstructures. These increase torsional loading by dynamic action as the ship rolls. This type ship must suffer severe torsional strains when being driven into seas a few points on the bow. It is interesting to see what Prof. Hovgaard had to say on this subject. In a memorandum signed on March 8, 1937, entitled "Strength of Main Deck—DD368—U.S.S. *Flusser*" he stated: "When a ship is driven at high speed against the

sea in a direction oblique to the waves and whenever she is subject to violent rolling in a seaway, great torsional moments occur. It is reported that the *Flusser,* at the time when the damage occurred, rolled excessively, and hence it may be inferred that the course of the ship was not directly head on to the sea. Under such circumstances she receives violent rolling impulses each time the bow plunges into an oncoming wave front, and torsional moments are created, which tend to rotate the whole ship about a longitudinal axis. This motion is resisted first by the inertia forces and whenever the stern rests on the slope of the following wave, also by a torsional couple of opposite sign. Thus torsional stresses will be created, which are liable to reach high figures where the plating is reduced in thickness and especially when sudden changes occur in the thickness.

"The torsional moments due to the buoyancy forces when a ship in sagging condition is resting obliquely on waves forward and aft, may be greatly augmented when the ship is rolling. At the end of each roll the inertia forces amidships meet little or no resistance from righting moments and are transmitted as torsional stress couples to the ends, where they are balanced by the buoyancy couples."

The purpose of this discussion has been to clarify two points which appeared obscure or misleading and to amplify the article by adding further data which appeared significant.

References

1. "Some Ship Strain Observations with a Simple Instrument," J. Lockwood Taylor—Trans. of Inst. Naval Arch., 1926.
2. "Longitudinal Stress in Ships During Heavy Weather," C. H. Stocks—Trans. of Liverpool. Engs. Society, 1937.
3. "Structural Stress in an Oil Tanker Under Service Conditions," I. C. Bridge—Trans. of Inst. of Naval Arch., 1938.

AUTHORS' REPLY TO CDR. BROWN'S DISCUSSION

CAPTAIN E. A. WRIGHT, USN

MR. JOHN VASTA

Cdr. Brown has brought to light many interesting points in his discussion of the paper. His remarks are thoroughly appreciated, and the additional data have enhanced considerably the value of the paper.

The authors recognize that the absolute stresses induced in a ship girder are dependent, among many other things, on both the type of ship involved (dry cargo or tanker) and the still water loading distribution. Since measurements taken at sea record changes in strain only, the data presented in the paper reflect this principal behavior. It was not intended, however, to minimize the effect of the still water bending moment since this

effect obviously shifts the datum stress plane. Even in still water, the absolute stress scale can not be accurately defined. Every structural shape has residual stresses of high magnitude, and every welded ship has locked-in and welding stresses of variable intensity. These effects make determination of an absolute stress a difficult task.

The case of the tanker *Cuyama* is somewhat confusing because of the large spread that exists between the measured moments (derived from strains) and the deduced moments. The authors are indebted to Capt. P. W. Snyder for noting that, contrary to page 702 of the paper, *Cuyama* does not follow the general pattern of higher sea stresses in sagging than in hogging. Cdr. Brown points out that "the true maximum stress of the *Cuyama* occurs during sagging," and this deduction is in harmony with tentative conclusion "c" of the paper.

The discussion on the effect of torsion is interesting but highly conjectural. Analysis of strain measurements taken at sea seem complicated enough without the effects of torsion, but it is surely a factor. It can be stated, however, that full scale static tests on ships loaded in torsion (SS *Philip Schuyler*) have failed to reveal any significant torsional stresses, even at points of geometrical discontinuities.

It was in the hope of stimulating just such technical curiosity and examination that the authors decided to give wider publicity to this study. Cdr. Brown found, as we did, that the available story on structural behavior in ships at sea is vague and exceedingly difficult to interpret and correlate. The paper, it is hoped, was but a beginning.

"Officer-Civilian Relationships in Semi-Military Technical Organizations"

By J. K. Fordyce

DISCUSSION

BY CAPT. J. M. FARRIN, USN

I have read Mr. Fordyce's extremely thought-provoking article with a great deal of interest. The problem of officer-civilian relationships is, of course, one of prime importance to the Bureau of Ships and its field activities. It is a problem requiring the understanding study of both the civilian and the officer and, of course, it is nothing new.

Back in 1945-1946, when we appeared to be heading for a return to normal peace-time conditions, a great deal of thought was given to the necessity of increasing the attractiveness of top civilian positions in and under the Bureau of Ships. An ad hoc committee, headed by Rear Admiral P. F. Lee, studied the problem at that time and made a report which pointed up a number of the specific points made in Mr. Fordyce's article and provided at least a start toward their solution.

To refer to a personal experience—in 1937 I was assigned, as an officer in design training, to the Bureau's Preliminary Design Branch, then under a civilian head. Some years later I served a tour of duty as officer head of the same branch. I found it a rare privilege to serve under the distinguished gentleman who was the branch head during the thirties and no less a privilege and pleasure in my later assignment to be associated with Mr. John Niedermair, the Bureau's internationally-known Technical Director of Ship Design. In neither instance did the matter of officer-civilian relationships prove any problem—for that matter, I cannot recall a single incident of this sort ever arising during those two tours of duty. My own experience has led me to believe, not that no problem exists but rather that the problem can be faced and solved with no loss of dignity, prestige, or satisfaction in the job for either party and regardless of whether an officer or a civilian is in the higher-level position.

Mr. Fordyce concludes that probably the best solution to the problem would be to open the top management jobs to both officers and civilians and to appoint the best qualified individual in each case. He points out that such a system would require a certain amount of rotation of civilian employees to give them the well-rounded backgrounds which contribute to success in the higher-level managerial positions. It seems to me that the author has based his conclusions on several incorrect premises.

First, his frequent references to officers as "consumer representatives" is not a fair analysis of the place or function of the Engineering Duty Officer group. The inference that these are operating line officers who are bringing the forces afloat viewpoint to the technical activities is, of course, far from the case. Let us examine the career of a typical Engineering Duty Officer. He starts, much as do our civilian engineers, as a better-than-average B.S. degree graduate, with a particular bent for engineering or scientific work. He has two or three years' duty afloat, at least one year of which is spent in an engineering assignment. He is then given an intensive three-year graduate course in Naval Construction and Engineering at one of the top technical schools in the country, receiving a Master of Science degree or the higher degree of Engineer. After completion of graduate work, he is given assignments of increasing responsibility in design, repair, or construction of ships, or in related work, at various Bureau of Ships' activities or on afloat staffs. If there is a better method of training engineers for positions of high-level management responsibility under the Bureau of Ships than this, I am sure the Bureau would be glad to know about it.

Have we not, then, in our Engineering Duty Officers precisely the background, training and experience that Mr. Fordyce recommends for the civilian engineers who would be groomed for top level positions? If so, we should examine whether it is preferable that the system envisage the use of officers, civilians, or a mixture of both in these positions. Obviously, it is possible to train a civilian group for these assignments. The State Department's Foreign Service group is an example of this. Something comparable to it is the British civilian Royal Corps of Naval Constructors. Both of these systems work satisfactorily. The question to decide is—would such a system work better for us than our present one? I think the answer would be "no" on at least two counts. First, we must take note of an important trend in the Navy, particularly since World War II—the recognition that Logistics is a definite and a most important responsibility of Command. This fact of life results in much more detailed directives and much

closer following of the technical bureaus' work by the various offices under the Chief of Naval Operations and by forces afloat than was formerly the case. This trend alone, resulting in much closer liaison, both in the Department of the Navy and in field activities, between operating and technical personnel is a strong argument for retaining officers in key management positions. Secondly, I believe that a selected group from among the civilians would encounter more friction, jealousy, and the "second class citizen" reaction from the rest of the civilian staff than our officer group does now.

The foregoing arguments against opening up all the Bureau's top-level management positions to filling by civilian personnel do not imply any complacency toward present conditions. It is, as Mr. Fordyce has pointed out, incumbent on management to do everything in its power to make civilian employment under the Bureau of Ships attractive to ambitious and able engineers and administrators. If it is agreed that the present system of training and assignment of Engineering Duty Officers is sound, certainly we should bend every effort to make the careers of our civilian personnel more attractive than they now are. Much can be done along these lines, even if we do not open all high-level positions under the Bureau to civilians. Action should most certainly be taken to improve the prestige, dignity, and latitude for independent action of the head civilian in each branch and other unit. As Mr. Fordyce has pointed out, merely writing the appropriate words in the position description sheet is not enough. There is room for plenty of education of the junior officers and the less experienced reserve officers by our senior Engineering Duty Officers, who themselves have a full realization of the importance of this matter. There is a great deal that can be done to bring increased recognition to the civilian group, through signing of correspondence, attendance at conferences, publication of papers and reports, and in countless other ways. Perhaps most important is a general and genuine recognition by the Engineering Duty Officer group of the co-equal status of our senior engineers and administrators. Certainly short shrift must be made of any such ridiculous sentiment as "an officer of the lowest rank has authority over the highest rated civilian."

No one appreciates more fully than the Engineering Duty Officer group that the outstanding record of our ships in World War II and their general recognition as the finest warships afloat is a tribute to the very high technical skill and devotion to duty of the civilian employees of the Department of the Navy. It would be foolish indeed if we fail to take any steps possible that would insure our attracting and retaining personnel of equal ability in the future.

BY CAPTAIN R. E. W. HARRISON, USNR

This article is a timely, judiciously sound and temperate appraisal of some situations which obviously call for constructive action.

By and large there exists no official manual of guidance available to the officer or to the civilian on this subject, hence there is the inevitable tendency for some of the phases of the situation to get out of control.

The following thoughts are offered, designed to be constructive. They are

based on forty years of studious observation of managerial relationships.

Insofar as the U.S. Navy is concerned, it is recommended that the following approach be adopted, i.e., consider the mission, it being no oversimplification to state that the mission is, "Serve the Fleet." If this be accepted, as it must, then only one question arises—"How do we accomplish the mission most effectively?"

There are a few fixed and certain answers to this basic question, and it is only on the fringes of human behaviorism where the ground is debatable. The fact is not debatable that we can only do our best work when we operate as a team. There are no substitutes—and no alternatives. The professional Navy knows it—it is in their very bones; and in their hearts, the civilians know it equally well and just as sincerely.

This leads to the next question. "How do we make a team out of the two elements under discussion?"

The following formula is the product of experience referred to above.

All human working relationships, to be thoroughly sound, must, of necessity, be based on sincere, mutual respect. At this point it is well to emphasize that the best attributes that any team manager can have at his disposal are:

1. The individual team member's self-respect.

2. The individual team member's pride of craftsmanship in the individual job well done, and more importantly, pride of accomplishment in the results achieved by the team as whole.

These are the truly valuable tools of good management.

As managers, we all need guidelines, and if the system under which we operate does not provide them, they must be generated. The following guidelines are suggested, backed by many years of results-getting experience.

1. Officers will accord to the civilian members of the team the same courteous respect and consideration that they automatically give to a brother officer in the same pay grade as the civilian.

2. The civilian component of the team will automatically and unquestionably accord the same consideration to the officer.

3. The officer in charge will regard his civilian staff component as the permanent continuing force which will automatically consolidate all good ground gained during his tour of duty, and will faithfully perpetuate his constructive ideas and policies until something superior is devised and approved by appropriate authority.

4. A log will be kept. The officer will require it and inspire it, but the senior civilian will make it, and its integrity, his personal responsibility. This log will constitute a running record of achievements, of projects completed or rejected, or in process. On relief, the officer will pass the log on to his successor at a conference attended by the supervisor civilians in the team.

5. A requirement of the policy is that all new staff members, both officer and civilian, be indoctrinated in these ground rules and procedure, and on every appropriate occasion, the officer and his senior civilians will emphasize the team spirit, judiciously reiterating as the occasion demands—that:

a. The Navy is a military organization, and as an entity is and must remain a well coordinated team.

b. The shore-bound component of the team, part civilian and part officer, can only register its full effectiveness if the mutual interdependence of each component (civilian and officer) be thoroughly integrated, for the accomplishment of the basic mission.

c. That the mission is paramount —in all things—in all situations— and at all times.

6. An important part of the mutual respect element is immediate recognition of the need for both civilians and officers to professionally develop their individual careers, that the two developments are complimentary. From the officer's viewpoint, the quality of professional excellence possessed by the civilian half of his team is the best kind of guarantee that a job will be well done. Likewise, the civilian contingent, when managed by a perceptive and professionally qualified officer, can have avenues of professional development opened up to them which conceivably could not be made available through any other channel.

The officer, temporarily assigned to a tour of duty to head up an engineering or similar professional activity, will automatically keep his whole team keyed up, by a personally demonstrated loyalty to the professional interests of all of his crew. Why? Because, by so doing, he inspires that will to achievement which has all important bearing on the accomplishment of the mission, i.e., "Service to the Fleet."

BOOK REVIEW

ADVANCED MECHANICS OF MATERIALS

By F. B. Seely and J. O. Smith

Published by John Wiley and Son

Reviewed by Mr. John Vasta

This is the second edition of a standard text that made its initial appearance some 20 years ago. The old material has been completely revised and additional chapters have been added. It may be stated, in fact, that the second edition is essentially a new book reflecting the progress made in the field of mechanics during the past two decades.

The book consists of six parts and several important appendices. Part 1 presents a discussion of the fundamental concepts of the subject, reviewing some of the more important methods of analysis. Here the usual theories of failures are summarized. Part 2 discusses, the elementary stress formulae used in the solution of static problems, and develops the method of analysis used in the determination of stress in several structural members. The general behavior of plates under bending action is treated first by the small deflection theory, and later by the large deflection theory. This part of the text makes frequent use of tables and graphs which facilitate solutions of engineering problems. Part 3 presents a discussion of the significance of the stress concentration factor as it occurs in engineering structures and in machine parts. General methods for reducing the harmful effects of the stress concentrations are indicated. Part 4 discusses the energy method for determining the relationship between loads and deflections. The familiar Castigliano's Theorem is followed by the method of "dummy" load analysis. Part 5 treats the inelastic behavior of structural members with emphasis on the effect of small inelastic strains. The results of the method are presented in convenient graphical forms by means of interaction curves. Part 6 considers the instability phenomen of structural members loaded in compression, and treats the buckling of thin-walled and slender structural components. Both the elastic and inelastic buckling are considered in this part.

The book contains selected references which suggest desirable sources of information for the student wishing to pursue the subject further. Two new appendices have been added to the original text: one presents pertinent discussion on the limits of the theory of elasticity, and emphasizes the importance for taking strain measurements on structural members; the other discusses the elastic membrane soap film analogy, a useful tool for the solution of torsional problems of complicated cross sections.

This second edition is a much improved text as compared with its predecessor. it should prove a valuable reference to all students engaged in the field of structural mechanics.

BOOK REVIEW

FATIGUE AND FRACTURE OF METALS

PUBLISHED BY TECHNOLOGY PRESS OF M.I.T. AND JOHN WILEY & SONS, NEW YORK

REVIEWED BY JOHN VASTA

Into the three hundred pages of this book is packed a concentrated dose of useful and stimulating engineering data on the fatigue strength and the brittle fracture of metals. It is indeed a rarity to see so much material so clearly condensed into one useful volume. The recognized specialists who prepared the articles have done a creditable job.

The book contains fourteen technical papers which were presented at a recent symposium held at M.I.T. Besides a survey of the existing knowledge of the subject of fatigue and fracture of metals, the book presents discussion of the fundamental nature of the internal mechanisms that control fatigue damage. The significance of the metallurgical phenomena, such as strain hardening and metallographical structure, is adequately reviewed. The book gives a survey of the service experience of many engineering structures where failure of metals was catastrophic. There is a discussion of research methods which will yield a realistic and reliable correlation between small scale laboratory tests and the prototype structure. The concepts of brittle behavior and crack propagation in metals are also ably treated. These should serve as a warning to the engineer that large structures can sometimes experience distress without any apparent reason. This book is considered a valuable reference, and is highly recommended to designers of engineering structures.

BOOK REVIEW

GENERAL BILLY MITCHELL; CHAMPION OF AIR DEFENSE

By Roger Burlingame

New York: McGraw-Hill Book Company, Inc., 1952. 192 Pages. $5.00

Acknowledgment

This book review was published in the March 1953 issue of "U.S. Naval Institute Proceedings." The reviewer is Commodore Dudley W. Knox, U.S. Navy (Retired), a founder of The Naval Historical Foundation and one of the U.S. Navy's best known historians.

This biography is well written and interesting. The style is glamorous and impressionistic rather than objective and factual. The case against the Navy, which is the primary target for criticism, is unfortunately built largely on half-truth and many crucial errors, resulting in marked distortion.

A basic fault is the failure to clarify the main issue between Mitchell and the Navy, which was whether naval aviation should be integrated with other forms of naval power, or, as Mitchell contended, should be excised from the Navy and joined with a super Air Force, separate from and independent from both Army and Navy.

A cardinal omission is non-recognition of the fact that a large group of naval aviators, more experienced and more competent in aviation than Mitchell, as a body were opposed to his efforts to separate aviation from the Navy, and instead strongly favored integration. Moreover these naval aviators, in addition to superiority in aviation were competent in naval affairs, in which field Mitchell was ignorant. So that on the whole, the judgment of the Navy's aviators on the question of whether or not to integrate naval aviation with the Navy, seemed obviously far superior to the opinions of Mitchell. And so subsequent war experience well proved. The real prophets deserving of high honor and respect do not include Mitchell. They are the gallant naval aviators who opposed him and steered the Navy clear of his false naval doctrines.

General Mitchell made so many prophecies that some of them were bound to be right. On these latter his biographer and other adherents base the claim that he was a great prophet, conveniently forgetting or omitting his many erroneous forecasts. Just for the record we might cite some of his "misses," as follows: "Airplane

carriers are useless instruments of war against first class powers." (Remember Pearl Harbor?); "The surface ship as an element of war is disappearing"; "If a naval war was attempted against Japan, for instance, the Japanese submarines and aircraft would sink the enemy fleet long before it came anywhere near their coast"; "Any attempt to transport large bodies of troops, munitions and supplies across a great stretch of ocean, by seacraft, as was done during World War I from the United States to Europe, would be an impossibility" (because of airplanes and submarines); "Land power has become a holding agent which occupies a place conquered by airpower. Seapower in its old role of defending a coastline has ceased to exist"; "The seas cannot be controlled through the agency of ships when such invincible enemies exist as aircraft and submarines"; "Today the principal weapon in the sea is the submarine"; "In the future the mere threat of bombing a town by an airforce will cause it to be evacuated"; "A superior airforce will dominate all sea areas when they act from land bases, and no seacraft, whether carrying aircraft or not, is able to contest their aerial supremacy"; "Effectiveness (of anti-air guns) is constantly diminishing and never can improve much." This reviewer doubts that any naval aviator ever prophesied so many gross inaccuracies, as proved later by the greatest war in history.

Another distortion in the book is the omission of what the Navy was doing to develop aviation after the Armistice of November, 1918, and before Mitchell started his "crusade" in the spring of 1919. Thus the impression is erroneously created that the Navy was indifferent towards aviation and negligent in its development. Within two weeks after the Armistice the Commander-in-Chief of the Fleet strongly recommended intensive development of the Fleet's air arm. In January, 1919, he began large-scale exercises of planes and the fleet, working together. Besides a variety of other maneuvers these included bombing attacks on ships underway, as an important feature. From its own extensive experience with bombing in France during the late war, the Navy was already thoroughly convinced of the vital importance of bombing in future naval warfare. In May of 1919, after a lengthy study of the whole aviation question, the General Board reported that "The development of fleet aviation is of paramount importance and must be undertaken immediately if the United States is to take its proper place as a naval power." Such development was undertaken very promptly.

As part of this general development, advantage was taken of the opportunity to use live bombs on several German ships which had been turned over to us by the Peace Treaty, on condition that they be sunk. Naturally the Navy desired to gain a maximum of information from such a rare opportunity. Under various conditions, different types and sizes of bombs, fuses, etc. were tried out, and so long as the target remained afloat she was inspected after each hit or near miss, to record the effect on different parts of the ship. It was all very scientific, except for General Mitchell's part.

The Army had been invited by the Navy to participate in sinking the ex-German battleship *Ostfriesland*. Mitchell's part in this affair is featured and dramatized in the book under review, with accuracy thrown to the winds. He is represented as participating against naval wishes. No mention is made of the Navy's invitation, nor of the Navy's lending his planes suitable compasses and bomb sights. The author states that the ship had survived "eighteen hits from 12- and 14-inch guns in the Battle of Jutland," whereas in fact she was not hit by gunfire in that battle. He also makes the absurd statement that "in the opinion of naval experts" the *Ostfriesland* was "unsinkable."

The truth is that Admiral Alfred W. Johnson who conducted the tests was among many naval officers who were surprised that she had not sunk on the previous day when 47 bombs aggregating 11 tons had been used against her, including five 1000-lb. bombs. Considerable damage had thus accumulated before the second day when Mitchell's planes sank her with six 2000-lb. bombs. Disregarding the courtesies that had been shown him, and disobeying repeated orders given him, Mitchell would not wait between bomb-drops for an inspection of the ship for scientific data, but continued to bomb at intervals of about two minutes until the ship went down.

After having badly distorted this affair in his dramatically written first chapter, the author summarizes the Navy's side of the case more than a hundred pages later. He admits that the Navy's contentions have "a certain reasonableness," but takes refuge in the contention that they "can never be proved." The fact is that there is ample documentary proof available, which he could have found with little effort.

With respect to the Japanese attack on Pearl Harbor the author writes on the assumption that the primary culpability for the disaster rested upon the Navy, quite overlooking the fact that officially as well as ethically Army airplanes had the major responsibility for the air defense, and that the first Japanese act was to destroy those planes on the ground.

BOOK REVIEW

THE ARMOR OF ORGANIZATION

By Alvin Brown

Published by the Hibbert Printing Company, 271 Madison Avenue, New York 16, N. Y. 586 Pages. $5.50

In view of a recent published statement that a former Secretary of Defense had testified before a congressional committee to the effect that blame for failure in the Army could not be placed on any individual but must be assessed against the entire one-and-a-quarter person organization, this book is not without timeliness.

It is a long book. It must be studied. It cannot be glossed through. It will be highly controversial. Certainly few experienced military career men, except those who have advanced to the age of retrospection where they can look back over their lives and assess them objectively and without the need for finding excuses, will accept it whole heartedly.

The book is a historical account of the development of military organization. It presents proof as to how the concept of staff grew, and how staff became a substitute for organization. The proof is strong but will have difficulty in overcoming bias.

It is an analysis of present military organization. It purports to expose two principal errors: the neglect to differentiate functions and the failure to delegate responsibility. These errors will be recognized by many, admitted perhaps by few.

It then shows how the principles of organization can be applied to military requirements so as to devise an effective organization for the Armed Forces. There will be opposition to the stated principles and to their applicability to the situation.

A very timely book. An important book. It should be read.

REAR ADMIRAL CHARLES LEES BRAND, U. S. NAVY
PRESIDENT, 1944

OBITUARY

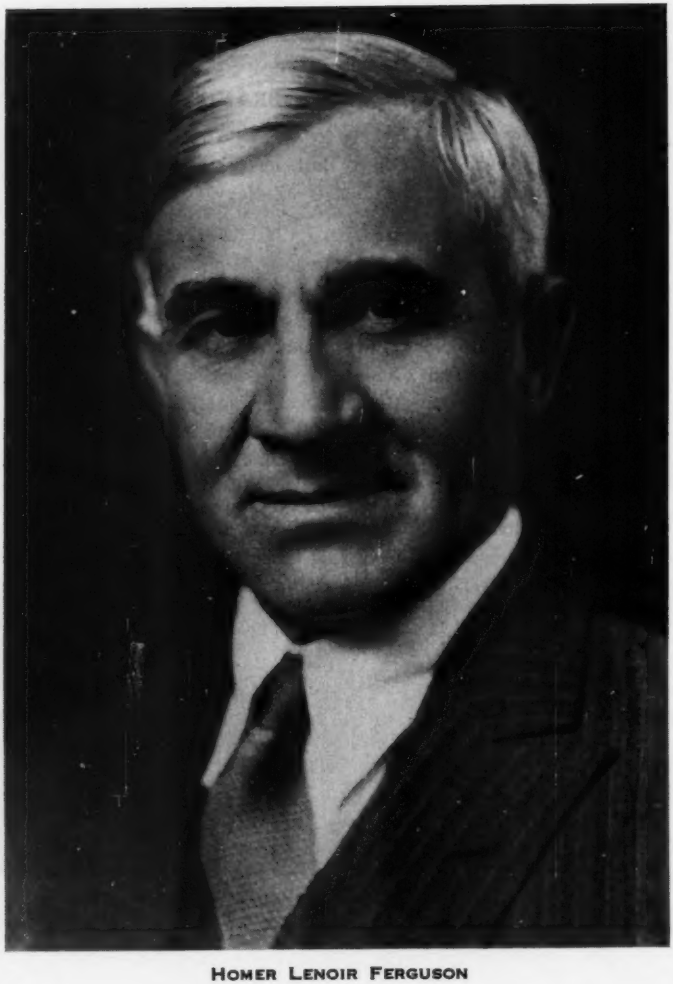
CHARLES LEES BRAND

On 18 April, 1953, the Society lost, by death, its 45th President, Rear Admiral Charles Lees Brand, U. S. Navy, Retired.

A Naval Academy graduate in the Class of 1910, Admiral Brand had completed more than forty years of distinguished Naval service when he retired in April, 1949. A member of the Construction Corps and since 1940 an Engineering Duty Officer, he saw service in both East and West Coast Navy Yards, and spent his last seven years of active duty in the Bureau of Ships. At the time of his retirement, he was Assistant Chief of the Bureau for Shipbuilding and Design. He was elected President of the Society and served in that capacity in 1944. Since then he has been an Honorary Member of the Society.

After his retirement Admiral Brand continued his shipbuilding associations as Naval Shipbuilding Consultant on the NATO Defense Production Board and as Shipbuilding Consultant for the United States Delegation in London. He retired from all official duties in 1952.

Admiral Brand died at the age of 65 at the U. S. Naval Hospital, Annapolis, Maryland.



HOMER LENOIR FERGUSON

OBITUARY

HOMER LENOIR FERGUSON

On 14 March 1953, death called one of the nation's outstanding industrialist and recognized leaders in the shipbuilding field. Mr. Homer Lenoir Ferguson died at the age of 80 after an active life of 61 years.

Mr. Ferguson graduated from the U. S. Naval Academy at the head of his class in 1892. Following four years of study under Sir John Biles at Glasgow University he served as a Naval Constructor in the Navy until 1905.

From 1905 until his death, Mr. Ferguson has been associated with the Newport News Shipbuilding and Drydock Company, starting as superintendent of hull construction and becoming president in 1912. He retired as president in July 1946 but continued as Chairman of the Board until his death.

Mr. Ferguson joined the American Society of Naval Engineers in 1905.

Since the publication of the February, 1953, Journal, the Society has learned of the following deaths among its members:

BRAND, CHARLES L., Honorary Member, Past President

COWAN, JOSEPH SAMUEL, Associate Member

FERGUSON, HOMER L., Naval Member

MEMBERSHIP CHANGES

The Society is pleased to announce the following additions to its membership since the publication of the February, 1953, JOURNAL:

NAVAL

Aldrich, Henry M., Sales Mgr. Naval & Marine Dept.,
Reeves Instruction Corp. N. Y., N. Y.,
Mail: 35 Michales Laes, New Hyde Park, L. I., N. Y.

Anderson, Gordon R., Lieutenant, USN,
Asst. Coordinator, Govt. Business, Fairbanks, Morse & Co.,
600 S. Michigan Ave., Chicago, Ill.

Anderson, Hubert Havan, Lieutenant, USN, Ret.,
Washington Representative,
Mail: 2701 Connecticut Ave., N. W., Washington, D. C.

Arnold, William Bennett, Vice President, Cargocaire Engineering Corp.,
Mail: Walnut Road, RFD, North Hampton, N. Y.

Averill, Roy, Commander, USNR,
Engineer, Youngstown Welding & Engineering Co., Youngstown, Ohio,
Mail: RFD 2, Melliger Road, Canfield, Ohio.

Bartlett, Dana Thomas, Chf. Carp., USNR,
Civil Engr., Maine State Highway Commission,
Mail: 65 Lincoln St., Augusta, Maine.

Baty, Norman Richard, Lieutenant, USNR,
Marine Engineer, Gulf Oil Co., Marine Dept.,
Mail: 412 Single Ave., Collins Park, New Castle, Del.

Bennett, Robert L., Lieutenant, USNR,
Machinery Officer, Sub-Group 1, Columbia River Group, Pacific,
Res. Flt., Tongue Poing, Astoria, Ore.

Campbell, Joseph S., Lt. Commander, USN, Ret.,
Hoffman Laboratories, Ind., 801 Washington Bldg., Washington, D. C.

Chamberland, Richard Leo, Ensign, USNR,
56 St. Louis Ave., Willimansett, Mass.

Champlin, Dean S., Chf. War. Gunner, USNR,
Selby, Battersby & Co., 5220 Whitby Ave., Philadelphia 3, Pa.

Cole, Frank Robert, Lieutenant (j.g.), USNR,
2858¼ Mascot St., Los Angeles 19, Calif.

Condon, Walter Francis, Jr., Lieutenant (j.g.), USNR,
523 Ramsell St., San Francisco, Calif.

Conkle, Glenn James, Ensign, USNR,
Babcock & Wilcox Co., Barberton, Ohio,
Mail: 222½ Way St., West, Barberton, Ohio.

DeMarais, Philip Odeus, Lieutenant (j.g.), USNR,
Worthington Corp.,
Mail: Ivy Hill Park Apts., Apt. 14-G, 220 Mt. Vernon Place, Newark 6. N. J.

Dolan, John William, Commander, USN,
Room 4512, Bureau of Ships, Navy Dept., Washington, D. C.

Drake, Rush S., Commander, USNR,
Rep. Hoffman Laboratories, Ind.,
801 Washington Bldg., Washington, D. C.

Estes, Ottis Tillman, Commander, USCG,
U. S. Coast Guard Headquarters, Washington, D. C.

Fish, Walter S., Asst. to Vice President,
Reeves Instrument Co., 215 E. 91st St., New York, N. Y.

Fitz Gerald, Paul Francis, Lieutenant, USN,
Student, Webb Institute of Naval Architecture,
Mail: 28-A, Stephens Oval, Glen Cove, L. I., N. Y.

Gardner, Howard Wyatt, Ensign, USN,
USS *Menifee* (APA 202), % Fleet P. O., San Francisco, Calif.

Gerber, Mitchell Leon, Lieutenant, USNR,
Mechanical Engineer, Bethlehem Sparrows Point Shipyard,
Sparrows Point, Md.

Gross, Royce L., R. Adml., USN, Ret.,
Chief Inspector & Welding Engr., Electric Boat Div., Groton, Conn.

Halota, John R.
3832 Beecher St., N. W., Washington, D. C.

Harrison, Hunter Craycroft, Lieutenant, USNR,
% Rheem Mfg. Co., Hill Bldg., 839 17th St., N. W., Washington, D. C.

Hazlett, Joseph Thomas, Jr., Lieutenant, USNR,
134 Morton Ave., Plainfield, N. J.

Hennessey, Thomas V., Commander, USN,
Room 4525, Bureau of Ships, Navy Dept., Washington, D. C.

Heyman, Robert, Lieutenant (j.g.), USN,
Office of Naval Material, Navy Dept.
Mail: 432 Leesburg Pike, Falls Church, Va.

Hodovanec, George, Lieutenant (j.g.), USNR,
2d Asst. Engr., United States Line,
Mail: 329 Mooney St., Olyphant, Pa.

Hoffman, Laurence Nelson, Lieutenant, USNR,
USS *Henricol* (APA 45), % Fleet P. O. San Francisco, Calif.

Holoubek, John J., Lieut. Commander, USNR,
Electronics Engr., Bureau of Ships, Navy Dept.,
Mail: 4804 20th St., North, Arlington, Va.

Hottel, Martin Perry, R. Adml., USN, Ret.,
Manager, Air Arm Div., Westinghouse Electric Corp., Baltimore 3, Md.

Ingersoll, James Hinchliff, Lieutenant, USNR,
Vice President and Works Mgr., Ingersoll Products Div., Borg Warner Corp.,
760 East Vine St., Kalamazoo, Mich.

Jarosh, Stanley Edward, Lieutenant, USN,
Manager, Industrial Dept., Westinghouse Electric Corp., 1625 16th St., N. W.,
Washington, D. C.

Johnson, Robert Milton, Lieutenant (j.g.), USN,
USS *Mulberry* (AN 27), % Fleet P. O., San Francisco, Calif.

Jones, Willard Lemuel, Commander, USCG,
Chief Engineering Div. 2d CG Dist., 8th & Oliver Sts., St. Louis, Mo.

Kassell, Bernard Maxwell, Commander, USN,
Apt. B-1, 291 So. Dinwiddie St., Arlington, Va.

Kloski, Leonard A., Lieut. Commander, USNR,
5602 Wilson Boulevard, Arlington, Va.

Leppert, George, Lieutenant, USNR,
Illinois Institute of Technology,
Mail: New Lennox, Ill.

McCrory, Thomas Stanton, Lieut. Commander, USNR,
Engineer, Baldwin-Lima-Hamilton Corp., Room 635 Wyatt Building,
777 14th St., N. W., Washington, D. C.

McGrath, William H., Lieutenant, USNR,
Mech. Engr., Hayelen, Harding & Buchaco, Boston, Mass.,
Mail: 200 Himsdale Ave., Arlington, Mass.

Maccoun, William Ellicott, Jr., Lieutenant, USNR,
Senior Naval Architect, Puget Sound Bridge & Dredging Co., Seattle, Wash.,
Mail: 9059 E. Shorewood Drive, Mercerls, Wash.

Mitchell, Charles Jordan, Lieutenant (j.g.), USNR,
USS *LST* 902, % Fleet P. O., San Francisco, Calif.

Morton, Donald Stewart, Ensign, USNR,
Mech. Engr., M. W. Kellogg Co.,
Mail: 84 California Ave., Hemstead, N. Y.

Mrozek, Anthony S., Lieutenant, USNR,
Mgr. Defense Conts., Ingersoll Products Div., Borg Warner Corp.,
Mail: 603 Glendale Blvd., Parchment, Mich.

Myles, Clyde W., Lieutenant, USNR,
5217 Wissioming, Glen Echo Heights, Md.

Noble, Albert G., Vice Adml., USN, Ret.,
Executive Vice President, Nordberg Mfg. Co.,
P. O. Box 1082, Milwaukee 1, Wis.

Noble, Kenneth Hill, R. Adml., USN Ret.,
Technical Adviser, Reeves Instrument Co.,
Mail: Crownsville, Md.

Noble, Lee F., Commander, USNR,
5102 Columbia Pike, Arlington, Va.

Padis, A. A., Lieutenant, USN,
Quarters A-16, Naval Base, Philadelphia 12, Pa.

Parker, Hubert C., Commander, USNR,
H. C. Parker Co., 1424 K St., N. W., Washington, D. C.

Pfefferkorn, Glenn Esra,
USS *Electron* (AKS 27), % Fleet P. O., San Francisco, Calif.

Prifold, George, Commander, USNR,
Manager, LTV Div., Ingersoll Products Div., Borg Warner Corp.,
Mail: 1810 N. Pitchin St., Kalamazoo, Mich.

Reardon, Donald J., Commander, USCGR,
Room 213, U. S. Appraisers Bldg., San Francisco 11, Calif.

Rice, Clarence Hagler, Lieut. Commander, USNR,
Marine Engr., 8th Dist., USCG, New Orleans, La.

Rullman, William Henry, Lieut. Commander, USNR,
Sales Engr., C. H. Wheeler Mfg. Co., Philadelphia, Pa.
Mail: 116 W. Beechtree Lane, Wayne, Pa.

Schiffel, Joseph William, Lieut. Commander, USNR,
Chief Engineer, LVT Div., Ingersoll Products Div., Borg Warner Corp.,
Mail: 2323 Grane Ave., Kalamazoo, Mich.

Shade, Howard Milton, Lieutenant, USNR,
Bureau of Ships, Navy Dept.,
Mail: Box 606 RFD 3, Alexandria, Va.

Shallenberg, Lowell W., Commander, USN,
U. S. Naval Engineering Experiment Station, Annapolis, Md.

Stengel, Joseph Frank, Jr., Lieutenant (j.g), USNR,
Vice President, Telephonics Corp., Park Ave., Huntington, L. I., N. Y.

Still, Donnell Moody, Lieutenant, USN,
Sales Engr., Sperry Gyroscope Co.,
Mail: 259 Schepis Ave., Fairlawn, N. J.

Sullivan, David C., Lieut. Commander, USNR,
Asst. to Div. Manager, Contracts Div., Raytheon Mfg. Co.,
Mail: 372 Weld St., West Roxbury, Mass.

Swed, Richard John, Lieutenant (j.g.), USN,
1059 Huntsbridge Road, Yonkers 4, N. Y.

Taylor, Alfred R., Captain, USN, Ret.,
Executive Engineer, Ultrasonic Corp., Cambridge, Mass.
Mail: 5 Bellingham St., Newton 61, Mass.

Thomas, Llewellyn I., Lieut. Commander, USNR,
Code 541, Bureau of Ships, Navy Dept., Washington, D. C.

Trimmer, John J., Lieut. Commander, USN,
104 Hottinger Ave., Whipper Barony, Naval Base, Charleston, S. C.

Vasalle, Bronall J.,
302 Nichols Ave., Norwood, Mass.

Watson, Frank Charles, Ensign, USNR,
Chief Engineer, Youngstown Welding & Engineer Co., Youngstown, Ohio.

Wegner, William, Lieutenant (j.g.), USN,
Student, Webb Inst. of Naval Architecture,
Mail: 10 Popular Place, Glen Cove, L. I., N. Y.

Weidner, C. Kenn, Captain (CECO) USNR,
Dean of School of Engineering American University of Beirut,
Beirut, Lebanese Republic.

Wilson, Thomas Bryan, Lieutenant (j.g.), USN,
Student, Webb Inst. of Naval Architecture,
Mail: 29-C, Stephan Oval, Glen Cove, L. I., N. Y.

Zikaras, Alvin John, Lieutenant, USNR,
Sales Engr., Marine Div., Farrel Birmingham Co.,
Mail: 38 Blackhouse Road, Trumbull, Conn.

CIVIL

Allen, Uriah L., Jr.,
Code 517-D, Bureau of Ships, Navy Dept.,
Mail: 12116 Bluhill Road, Silver Spring, Md.

Arnold, J. E., Division Manager,
Consolidated Vultee Aircraft Corp., Dangerfield, Texas.

Benoit, Walter E., Division Manager,
Electronics Division Westinghouse Electric Corp.,
2519 Wilkens Ave., Baltimore, Md.

Bregi, Ben F., Executive Engineer,
National Broach & Machine Co.,
Mail: 1120 Whittier Road, Grosse Point 30, Mich.

Bumbaugh, Frank T., Manager, Alloy Sales (Armor Plate),
U. S. Steel Corporation, 525 William Place, Pittsburgh 30, Pa.

Burrows, William Russell, Jr., Manager, Mfg. & New Ordnance Dept.,
General Electric Co.,
Mail: 100 Plastics Ave., Pittsfield, Mass.

Campani, John, Chief Engineer,
Target Rock Corp., Telephonics Bldg., Huntington, N. Y.

Claspy, Hugh James, Chief Engineer,
The Phoenix Glass Co., Monaca, Pa.

Clifford, Christopher J., Manager,
Navy Contracting Group, RCA Div.,
Mail: Haddon Hills Apts., Apt. 131A, Haddonfield, N. J.

Cooper, Laurence H., General Manager,
Aircraft Division, Rheem Mfg. Co.,
Mail: 11711 Woodruff Ave., Downey, Calif.

Craig, Robert Bradley, Assistant to President,
Fairbanks, Morse & Co.,
Mail: 1715 21st St., N. W., Washington, D. C.

Curtis, Richard Cooper, Chief Engineer,
Hazeltine Electronics Corp.,
Mail: Old Woodbury Road, Old Woodbury, L. I., N. Y.

Dennison, Edward S., Consulting Engineer,
Electric Boat Div., General Dynamics Corp.,
Mail: % Thames Club, New London, Conn.

Dewey, Chalmer B., Sr., Vice President,
Reeves Instrument Co.,
Mail: 6 Short Drive, Manhasset, L. I., N. Y.

Dixon, Robert K., Manager, Defense Contract Dept., Receiving Tube Div..
Raytheon Mfg. Co., 55 Chapel St., Newton 58, Mass.

Dunn, Thomas William, Special Project Director,
Electric Boat Division, Groton, Conn.

Erickson, Paul J., Asst. to Vice President,
Gibbs & Cox, Inc.,
Mail: 364 Fairmount Road, Ridgewood, N. J.

Grillo, Joseph E., Manager, Magnetic Amplifier Div.,
Bogue Electric Co., 52 Iowa St., Paterson, N. J.

Guinter, David Halsted, Contract Adm. for Naval Contracts,
Bureau of Ships, Sperry Gyroscope Co.,
Mail: 20 Woodside Ave., Baldwin, N. Y.

Hadley, Jesse Mowbray, Assistant to President,
Bendix Aviation Corp.,
Mail: 1333 G St., N. W., Washington, D. C.

Hamilton, L. L., Application Engineer,
Knolls Atomic Power Laboratory, General Electric Co.
Mail: 1435 Baker Ave., Schenectady, N. Y.

Hiltebrant, Arthur, General Manager, New York District,
Bethlehem Shipbuilding Co., Shipbuilding Div.,
25 Broadway, New York 4, N. Y.

Holden, Donald Archer, Asst. Chf. Engr.,
Newport News Shipbuilding & Dry Dock Co., Newport News, Va.

Hunter, John Beveridge, Asst. to Vice President,
Bethlehem Steel Co., Shipbuilding Division,
25 Broadway, New York 4, N. Y.

Hurlburt, James Sturges, District Rep.,
General Electric Co., 777 14th St., Washington, D. C.

Lackey, William Harrison, Manager, Plate Sales,
Lukens Steel Co., Coatesville, Pa.

Leonard, John Sawyer, Chief Marine Engineer,
Electric Boat Div., General Dynamics Corp., Groton, Conn.

Logan, John W., Manager, Application Engineering Section,
Knolls Atomic Power Laboratory, General Electric Co.,
Mail: P. O. Box 1072, Schenectady, N. Y.

Lyons, William Joseph, Engineer, Elliott Co., Room 1001,
Washington Gas & Light Co., 790 11th St., N. W., Washington, D. C.

McCoy, Rawley D., Chief Engineer,
Reeves Instrument Co., 215 E. 91st St., New York 28, N. Y.

McMahill, Victor W., Jr.,
Westinghouse Electric Corp., 1625 K St., N. W., Washington, D. C.

Miller, Richard H., Product Rep., Armor Products Alloy Sales,
U. S. Steel Corp., 525 William Penn Place, Pittsburgh 30, Pa.

Obstler, Joseph, President & Manager, Derrick & Hoist Corp.,
24-16 Bridge Plaza Sq., Long Island City 1, N. Y.

Palmer, James Primrose, Chief Electrical Engineer,
Electric Boat Div., Groton, Conn.

Parkhurst, B. A., Vice President, Reeves Instrument Co.,
215 E. 91st St., New York 28, N. Y.

Pirner, Edward J., Partner, P. A. Co. Machine & Tool Co.,
Mail: 39 Adams St., Garden City, N. Y.

Praeg, Walter S., President, National Broach & Machine Co.,
Mail: 5600 St. Jean, Detroit 24, Mich.

Radford, Lawrence, Technical Rep., Farrand Optical Co., New York,
Mail: 4000 Cathedral Ave., Washington, D. C.

Rivers, Gene Rzeczkowski, Manager Govt. Sales, RCA Victor Div.,
Mail: 273 W. 10th St., New York 14, N. Y.

Rosenblatt, Lester, Naval Architect, Partner,
M. Rosenblatt & Co., 111 Broadway, New York 6, N. Y.

Ruiz, Ruperto, Naval Architect, N. Y. Naval Shipyard,
Mail: Apt. 1-C, 611 W. 158th St., New York 32, N. Y.

Russell, William Bradford, President,
Kewanee-Ross Corp., Kewanee, Ill.

Schreiber, Harry A., Marine Engr., Lidgerwood Industries, Inc.,
Mail: 63 Lucille St., Hemstead, N. Y.

Schwan, Arthur C., Manager, Newark Plant,
DACO Machine Tool Co., 125 First St., Newark, N. J.

Shaw, Harmon Lee, Vice President & Director of Engineering,
Perfecting Service Co., 232 Atendo Ave., Charlotte, N. C.

Shugg, Carleton, Manager, Electric Boat Div.,
General Dynamics Corp., Groton, Conn.

Sloan, George Romney, Sales Engineer, General Electric Co.,
Wyatt Bldg., 777 14th St., N. W., Washington, D. C.

Smith, Joe D., Hull Supt., Todd Shipyards Corp., Houston Div.,
Mail: 801 West Ellaine St., Pasadena, Texas.

Snyder, Frank Lloyd, Manager, Aviation Gas Turbine Div.,
Westinghouse Electric Co., Pittsburgh, Pa.

Sparrell, Lester Strong, Manager Sales, Shipbuilding Div.,
Bethlehem Steel Co., 25 Broadway, New York 4, N. Y.

Stauber, Alois A., Managing Partner, DACO Machinery & Tool Co.,
202 Tillary St., Brooklyn 1, N. Y.

Strenger, William Theodore, Vice President, Engineering N.S.T. Corp.,
2642 S. 5th St., Philadelphia 48, Pa.

Swennes, Benjamin A., Director of Engineering, LVD Div.,
Ingersoll Products Div., Borg Warner Corp.,
Mail: 923 West Kalamazoo Ave., Kalamazoo, Mich.

Tompkins, Donald D., Director DACO Machine & Tool Co.,
Mail: Old Farm Road, Baskim Ridge, N. J.

Todd, John W., Asst. Manager, Alloy Sales,
U. S. Steel Corp., 525 William Penn Place, Pittsburgh, Pa.

Valk, Robert Earl, Works Manager, National Supply Co.,
Tulsa & Houston Plants, Houston, Texas.

Walker, Henry Prior, Sec. Head, Code 560 K, Bureau of Ships, Navy Dept.,
Mail: 9412 Worth Ave., Silver Spring, Md.

Warner, Leslie Harry, President, Automatic Electric Sales Corp.,
1033 W. Van Buren St., Chicago, Ill.

Weber, Paul J., Head Acoustics Sec., Bureau of Ships, Navy Dept.,
Mail: RFD, Box 213, Beltsville, Md.

Woodbury, William F., Sales Manager, Halzeltine Electronics Corp.,
28-27 Little Neck Parkway, Little Neck, L. I., N. Y.

Zimmerman, Charles E., President, Consultants & Designers, Inc..
251 W. 42nd St., New York 36, N. Y.

ASSOCIATE

Alexander, David Ord, Field Project Engineer, T. W. McGuire Co.,
Mail: 2033 Rosemont Ave., N. W., Washington 10, D. C.

Allen, Delos Keller, Staff Engr., Automatic Electric Sales Corp.,
Room 601, Washington Building, Washington 5, D. C.

Baldridge, Charles Bayard, Asst. Secretary, Cleveland Diesel Engine Div., GMC,
2160 W. 106th St., Cleveland, Ohio

Barth, H. Wade, Chief Engineer, Cleveland Diesel Engine Div., GMC,
2160 W. 106th St., Cleveland 11, Ohio.

Brophy, John Wilbur, Works Manager, Cleveland Diesel Engine Div., GMC,
Mail: 21448 South Park Drive, Fairview Park 26, Ohio.

Ceva, Joseph, Sales Rep., Federal Telephone and Radio Co.,
100 Kingsland Road, Clifton, N. J.

Colman, W. T.,
Baldwin-Lima-Hamilton Corp, Lima, Ohio.

Cuneo, John A., General Sales Manager, Fairbanks, Morse & Co.,
600 South Michigan Ave., Chicago, Ill.

Davidson, Harvey Dean, Asst. Sales Manager, Blackmer Pump Co.,
Mail: 1449 Johnston St., Grand Rapids, Mich.

Goodwin, Macdonald, Washington Rep., Bogue Electric Mfg. Co.,
2430 Pennsylvania Ave., N. W., Washington, D. C.

Herzog, Warren George, Sales Engineer,
Federal Telephone & Radio Co., Clifton, N. J.

Kinney, Robert M., Sales Engineer, Baldwin-Kima-Hamilton Corp.,
Room 642, Wyatt Bldg., 777 14th St., N. W., Washington, D. C.

Knight, Arthur Rhodes, President, American Electric Welding Co.,
708 South Caroline St., Baltimore 31, Md.

Koontz, Ellwood H., Sales Engineer, Reliance Electric Engineering Co.,
Mail: 417 Woodlawn Ave., Westfield, N. J.

Lanthorn, Elmer Holzer, General Sales Mgr., Blackmer Pump Co.,
Mail: 1809 Century Ave., S. W., Grand Rapids 9, Mich.

Lee, James G., Washington Rep., Shipbuilding Division,
Bethlehem Steel Co., American Security Bldg., Washington, D. C.

Luby, F. Charles,
3452 Martha Custis Drive, Parkfairfax, Alexandria, Va.

Lynn, George H., Sales Manager,
Baldwin-Lima-Hamilton Corp, Hamilton, Ohio.

McDermott, Frank W., Sales Rep., Federal Telephone & Radio Co.,
100 Kingsland Road, Clifton, N. J.

McKee, John J., Major, USAFR, Asst. Mgr., Washington, D. C.,
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The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

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Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which insufficient material is already on hand.

SUBJECT MATTER AND AUTHORS

To assist the editor in programming future issues, the help of all members is solicited. To make it easy, the last page in this issue is readily detachable as you will find. This page has blanks for two entries.

(a) What subject would you, as a member, like to see covered by an article in the JOURNAL.

and

(b) Who do you consider best qualified to prepare such an article authoritatively, and what is his address (if you know).

Any of these forms which are filled in and mailed to the Society will be received with thanks and the editor will follow up to get the suggested articles prepared.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

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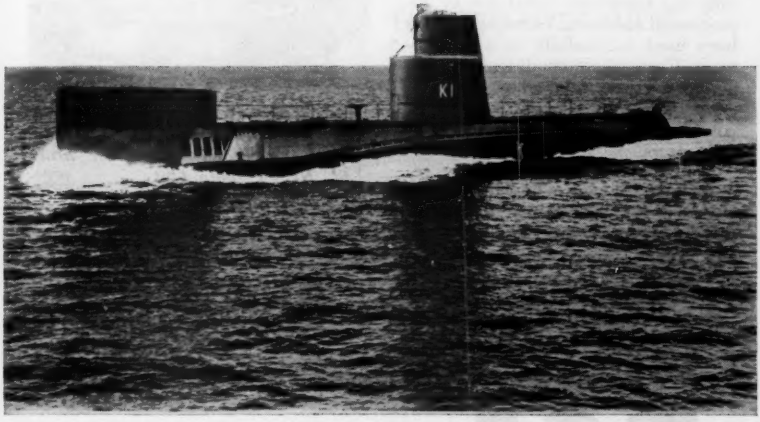

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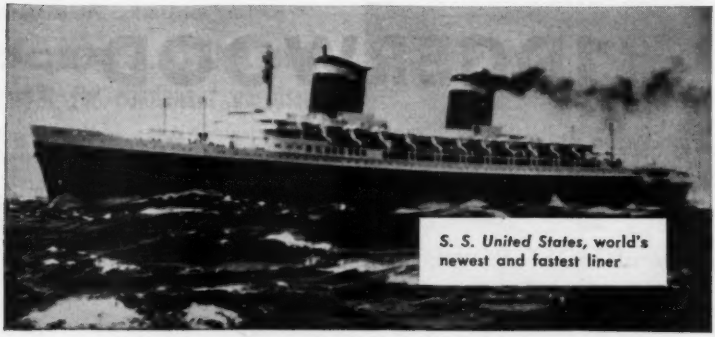

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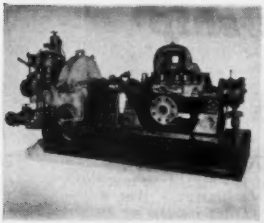
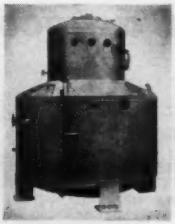
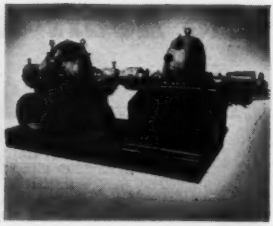

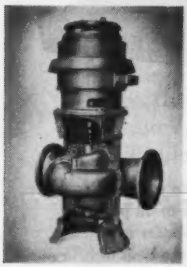
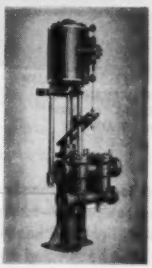
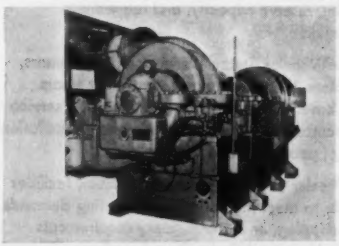
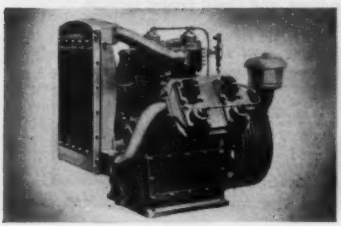

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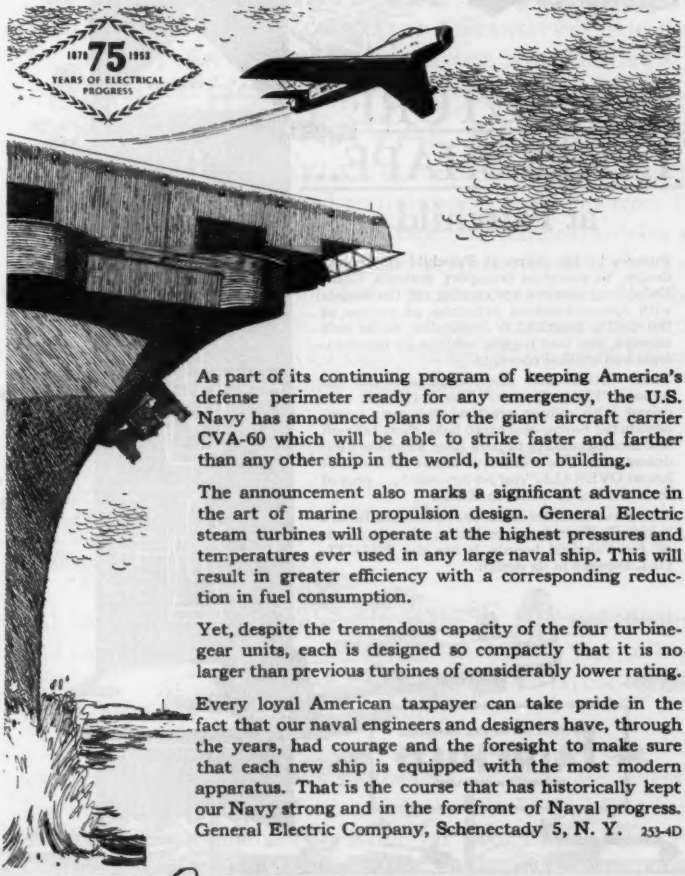

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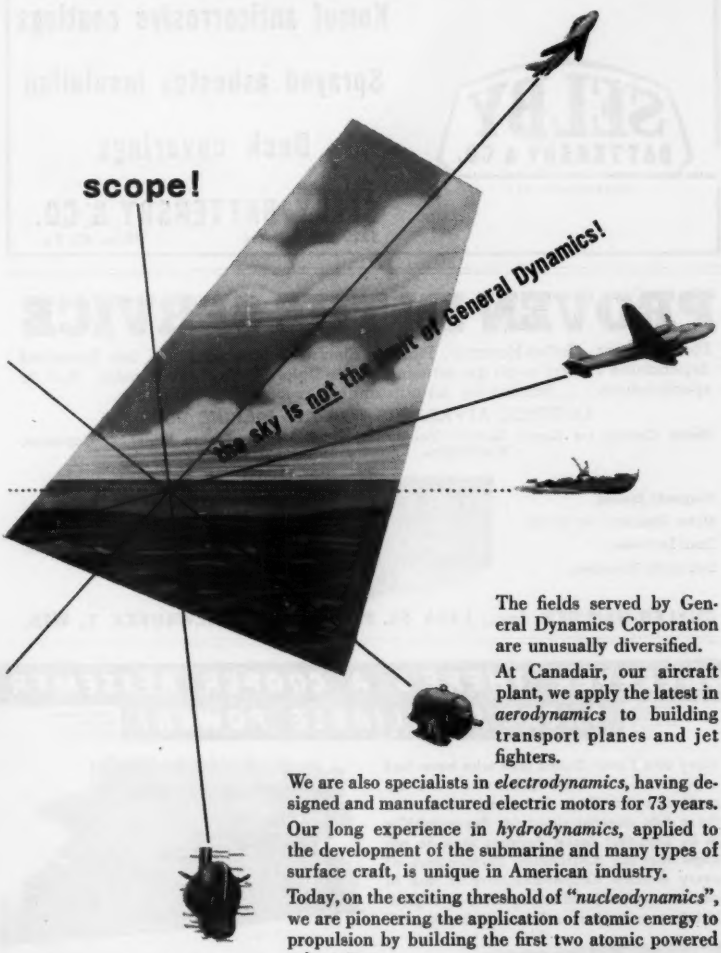

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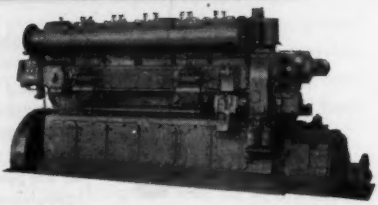

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1890 Assistant Engineer W. M. MCFARLAND, U. S. Navy
1891 Assistant Engineer EMIL THEISS, U. S. Navy
1892-93 P. A. Engineer W. M. MCFARLAND, U. S. Navy
1894-95 P. A. Engineer R. S. GRIFFIN, U. S. Navy
1896-97 P. A. Engineer F. C. BIEG, U. S. Navy
1898 P. A. Engineer W. M. MCFARLAND, U. S. Navy
1899 Chief Engineer A. B. WILLITS, U. S. Navy
1900 Lt. Comdr. A. B. WILLITS, U. S. Navy
1901 Lieutenant B. C. BRYAN, U. S. Navy
1902 Lieutenant C. W. DYSON, U. S. Navy
1903 Lt. Comdr. JOHN R. EDWARDS, U. S. Navy
1904 Lieutenant M. E. REED, U. S. Navy
1905 Lieutenant W. W. WHITE, U. S. Navy
1906 Lieutenant C. K. MALLORY, U. S. Navy
1907-08 Lt. Comdr. T. C. FENTON, U. S. Navy
1909-10 Lieutenant H. C. DINGER, U. S. Navy
1911 Commander U. T. HOLMES, U. S. Navy
1912 Lieutenant JOHN HALLIGAN, U. S. Navy; Lt. Comdr. E. L. BENNETT, U. S. Navy
1913 Lieutenant O. L. COX, U. S. Navy
1914 Lt. Comdr. H. C. DINGER, U. S. Navy
1915-16 Lieutenant A. T. CHURCH, U. S. Navy
1917 Lt. Comdr. J. O. RICHARDSON, U. S. Navy; Lt. Comdr. F. W. STERLING, U. S. Navy, Retired
1918 Lt. Comdr. F. W. STERLING, U. S. Navy, Retired
1919 Lt. Comdr. F. W. STERLING, U. S. Navy, Retired; Commander J. S. EVANS, U. S. Navy
1920 Commander J. S. EVANS, U. S. Navy
1921 Commander J. S. EVANS, U. S. Navy; Commander S. M. ROBINSON, U. S. Navy
1922-23 Commander S. M. ROBINSON, U. S. Navy
1924-25 Commander BRYSON BRUCE, U. S. Navy
1926 Commander A. M. CHARLTON, U. S. Navy
1927 Commander H. B. HIRD, U. S. Navy
1928 Commander H. B. HIRD, U. S. Navy; Captain O. L. COX, U. S. Navy
1929-30 Commander H. T. SMITH, U. S. Navy
1931 Captain O. L. COX, U. S. Navy
1932 Commander H. F. D. DAVIS, U. S. Navy
1933-34 Commander H. B. HIRD, U. S. Navy
1935 Commander C. S. GILLETTE, U. S. Navy
1936 Commander C. S. GILLETTE, U. S. Navy; Commander ROGER W. PAINE, U. S. Navy
1937 Commander ROGER W. PAINE, U. S. Navy
1938 Commander ROGER W. PAINE, U. S. Navy; Lt. Comdr. GUY CHADWICK, U. S. Navy
1939-40 Lt. Comdr. GUY CHADWICK, U. S. Navy
1940-44 Captain J. E. HAMILTON, U. S. Navy
1945 Commander R. T. SUTHERLAND, JR., U. S. Navy
1945-48 Captain F. W. WALTON, U. S. Navy